Treatment of osteochondral defects of the talus

Christiaan van Bergen

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Christiaan J.A. van Bergen

Colophon

Coverdesign/Layout: Ferdinand van Nispen, Citroenvlinder-dtp.nl, Bilthoven, the Netherlands & Christiaan van Bergen
Print: GVO drukkers & vormgevers B.V., Ede, the Netherlands
ISBN: 978-90-6464-742-0

The publication of this thesis was kindly supported by:

AE Sensors
AMC Graduate School
Amphia ziekenhuis
Anna Fonds
Arthrex
Arthrosurface
B&Co
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ChipSoft
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George In der Maur orthopedische schoentechniek
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TREATMENT OF OSTEOCHONDRAL DEFECTS OF THE TALUS

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad van doctor
aan de Universiteit van Amsterdam
op gezag van de Rector Magnificus
prof. dr. D.C. van den Boom
ten overstaan van een door het college voor promoties ingestelde commissie,
in het openbaar te verdedigen in de Agnietenkapel
op dinsdag 21 januari 2014, te 14.00 uur

door
Christiaan Johannes Augustinus van Bergen
geboren te Wijk bij Duurstede

Promotiecommissie

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Faculteit der Geneeskunde

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Chapter 1

General introduction

Historical perspective

An osteochondral defect or lesion involves the articular cartilage and the subchondral bone. The challenge of treating osteochondral defects and cartilage diseases in general has been recognized for a long time. In 1743, Hunter stated that "From Hippocrates down to the present age, ulcerated cartilage is a troublesome disease; when destroyed, it is not recovered".[191] In 1856, Monro first reported the presence of cartilaginous bodies.[290] König in 1888 first used the term *osteochondritis dissecans* (dissecans, derived from the Latin word *dissec,* which means to separate) to describe loose bodies in the knee joint, theorizing that they were caused by spontaneous necrosis of bone or an inflammatory process.[227] In 1922, Kappis noted the similarity of lesions of the ankle to those found in the knee and referred to osteochondritis dissecans of the ankle.[206] In 1932, Rendu reported an intra-articular fracture of the talus that appeared to be similar in nature to the lesion of osteochondritis dissecans.[332]

In 1953, Rödén et al. reported on 55 osteochondritis dissecans-like lesions of the talus.[335] They concluded that almost all of the lesions occurring laterally in the talus were secondary to trauma. Conversely, a large percentage of the medial lesions in their series were not secondary to trauma. Berndt and Harty in 1959 demonstrated that both the medial and lateral lesions of osteochondritis dissecans of the talus were in reality transchondral (osteochondral) fractures caused by trauma.[49] In their classic work, 43% of the lesions were noted to be in the lateral portion, usually the middle third of the talus, while 57% were noted to be in the medial portion, usually the posterior third.

Etiology

Nowadays, it is widely accepted that a traumatic insult is the most frequent etiologic factor in osteochondral defects (OCDs) of the talus. Trauma has been reported in 93% to 98% of lateral talar lesions and in 61% to 70% of medial lesions.[49,135,439]

Ankle sprains cause intra-articular pressure impact and have a prominent role in the development of traumatic OCDs (Figure 1).[230,422] The trauma causing the lesion can be a single event or a series of less intense (micro) traumas, which may remain unrecognized in some cases.[63,344] Lateral lesions usually are shallow and oval and caused by a shear mechanism. In contrast, medial lesions usually are deep and cup shaped and caused by torsional impaction

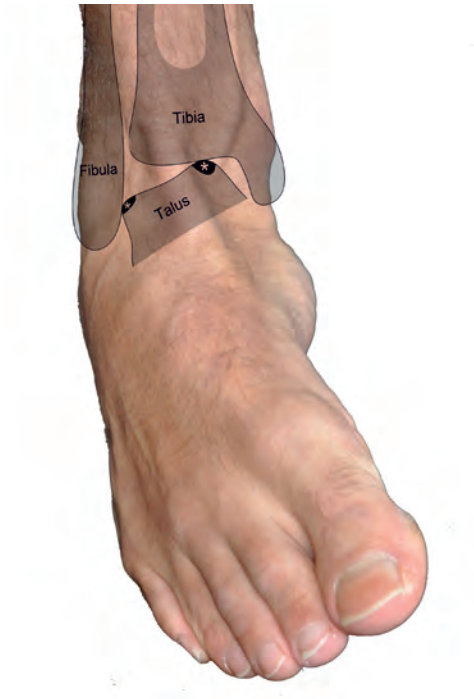

Figure 1. During an ankle sprain, the talus twists inside the ankle mortise. Osteochondral talar defects can be caused by local high compression in the articulation during this movement and are typically localized on the medial or lateral talar dome (*).

and axial loading of the talocrural joint. Rotation of the talus inside the ankle mortise during an ankle sprain can damage the cartilage lining, leading to bruising and subsequent softening of the cartilage or cracking of the cartilage with subsequent delamination. Separation in the upper layer of the cartilage occurs as a result of shear stresses. Alternatively, separation may occur in the subchondral bone, giving rise to a subchondral bone lesion. Fragments may break off and float loose in the ankle joint, or they may remain partially attached and stay in position.

Yet, not all patients report a history of ankle injury. The etiology of nontraumatic, idiopathic lesions may involve ischemia, necrosis, or genetics.[344] OCDs of the talus have been described in identical twins and siblings.[18,455] Furthermore, the defect is bilateral in 4% to 7% of the patients.[49,69] These facts suggest a nontraumatic origin and possibly a genetic predisposition.

Epidemiology

The most common site of osteochondral lesions is the knee, followed by the ankle and elbow.[63] Symptomatic OCDs of the talus usually appear in the second or third decade of life.[458] Men are affected more often than women.[458] The exact incidence of these lesions in the general population is unknown. Approximately 1 in 10,000 people per day suffers an ankle injury.[303] In athletes, this number can be as high as 9.4 per 10,000 athlete-exposures during active competition.[298] Talar OCDs occur in 15% to 25% of these injuries.[20] In the military, the overall incidence of OCDs has been reported 27 per 100,000 person-years.[306] A cadaver study using 72 paired ankles found (osteo)chondral talocrural lesions in 58 (81%) specimens, of which two thirds were on the talus.[88] These data suggest that OCDs are common but not always cause symptoms.

In light of increased awareness and continued evolution of imaging and treatment modalities, more attention has been given to the diagnosis of OCD during the past decades. In the 1990s and early 2000s, full thickness talar defects were found in 3% to 4% of patients with lateral ligament rupture or chronic ankle instability.[106,184,422] Later, studies reported OCD rates of 19% to 21% in patients with chronic ankle instability.[127,242] An incidence of up to 71% has been reported in patients with ankle fractures.[11,259,376]

Cartilage physiology

Articular cartilage consists mainly of extracellular matrix and a sparse population of chondrocytes. The extracellular matrix consists of collagen, hyaluronic acid, proteoglycans, and a small quantity of glycoproteins. Chondrocytes lie in groups in the lacunae of the extracellular matrix they produce.[204] Cartilage does not contain lymph vessels or nerves and has a slow metabolism.[204] It is avascular and is nourished by diffusion from the intra-articular synovial fluid. Water accounts for approximately 75% of the total weight of the cartilage. It functions as a transport medium. The frictional resistance of the water through the pores of the extracellular matrix and the pressurization of the water are the basic mechanisms from which articular cartilage derives its ability to support very high joint loads.

The cartilage of the talar dome is thin when compared with that of other joint surfaces. The mean cartilage thickness of the talar dome is in the range 1.2 to 1.4 mm.[354,372,444] In comparison, the average thickness of the cartilage in the hip and knee is 1.6 mm (range, 1.4 – 2.0 mm) and 2.2 mm (range, 1.7 – 2.6 mm), respectively.[354]

The thickness of the cartilage appears to be related to the congruence of a joint. The

ankle (with the thinnest articular cartilage) is a congruent joint, and the knee (with the thickest cartilage) is an incongruent joint.[359] It has been hypothesized that congruent joint surfaces are covered only by thin articular cartilage because the compressive loads are spread over a wide area, decreasing local joint stresses.[354] Incongruent joints are covered by thicker cartilage, which deforms more easily.

Cartilage is able to withstand compressive stress because of the interaction of its fluid and solid components. Its viscoelasticity is based on the electrostatic connections between collagen fibers and glycosaminoglycan (GAG) side chains of the proteoglycans, the flexibility and sliding qualities of the collagen fibers, and the displacement of water in cartilage.[204] The water is a dialysate of synovial fluid. It is incompressible but able to flow. It is contained in the matrix by the negatively loaded GAGs. Furthermore, the cartilage matrix resembles a sponge with directional pores; the small diameter of these functional pores and their arrangement in circuitous tunnels (created by the hydrophilic collagen and proteoglycan matrix components) offers considerable resistance to interstitial fluid flow. These characteristics provide adequate containment for the fluid to support the loads that joints sustain. Herberhold et al. studied the effect of patellofemoral compression during a 4-hour continuous static loading of 150% of body weight.[183] The maximal thickness reduction was 57% in patellar cartilage. These findings suggest that more than 50% of the interstitial fluid can be displaced from the matrix.[183] When one part of the joint is in compression, fluid flows from the loaded area to the unloaded area, thereby increasing the load-bearing area and decreasing the stress per unit area.[433]

The load-bearing area of the ankle joint is relatively small compared to the forces it transmits.[319,323] The load on the remaining cartilage increases when the contact surface area decreases in size, for example, after a malreduction of an ankle fracture or by an OCD. Ramsey and Hamilton found that a 1-mm lateral talar shift, as occurs after an ankle fracture malunion, reduces the contact area by 42%, and a 2-mm lateral shift reduces the contact area by 58%.[323] A 1-mm shift generally is considered acceptable, while a 2-mm shift should be surgically corrected because of the high risk of degenerative changes.[203] Apparently, the talar cartilage can adapt to an increase in contact stress as great as 42%. These findings concur with studies on contact stresses caused by OCDs. Christensen et al. evaluated the effect of talar OCDs graduated in size.[80] Significant changes in contact stresses were demonstrated only for larger lesions (diameter, ≥15 mm). Likewise, Hunt et al. studied progressively larger OCDs up to 12 mm and found no change in peak stress magnitude.[189] It has been postulated by van Dijk that the increase in load caused by a small OCD probably is not large enough to cause damage to the remaining cartilage in a normally aligned ankle.[434] However, any varus or valgus malalignment increases the likelihood of cartilage damage by high contact stresses.[219,382]

Importance of the subchondral bone

Articular cartilage is supported by the subchondral bone plate. The subchondral bone is crucial for the load-bearing capacity of the joint and for survival of chondrocytes.[16] It has been suggested that the release of soluble factors from subchondral bone may influence chondrocyte survival.[16]

Van Dijk has underlined the importance of the subchondral bone in talar OCDs.[433,434] The morphologic features suggest that the main area of action is around the subchondral bone plate.[221] Samples harvested from patients with OCDs of the knee all have (micro) fractured areas in the subchondral and underlying cancellous bone, besides a loss of GAGs from the damaged extracellular cartilage matrix and

a decrease in the number of chondrocytes.[221] Subchondral bone remodelling and areas of enhanced bone resorption are common.[221] Damaged subchondral bone is less able to support the overlying cartilage, and cartilage that is not supported by the underlying bone plate loses proteoglycans and glycoprotein, which causes a decrease in water containment.[64,204,320]

In a healthy joint, the cartilage fluid is not able to enter the subchondral plate. Van Dijk et al. have theorized that traumatic microfractures of the subchondral bone plate allow the fluid not only to flow within the cartilage but also to enter the subchondral bone through defects in the subchondral bone surface.[433] Every step or other load-bearing activity causes fluid to be pressed out of the cartilage and into the microfractured areas of the subchondral bone.[433] Similarly, the synovial fluid of the ankle joint may be pressed through the (micro) defect in the cartilage layer into the damaged area of the subchondral bone.[349] Different investigations have supported the theory.[87,330] The high local fluid pressure can lead to osteonecrosis, bone resorption, and formation of lytic areas, causing a cyst.[111,345,421] A vicious circle begins, in which damage to the overlying cartilage leads to further subchondral bone damage, and the cartilage is further damaged because the underlying bone is unable to provide support.[434]

Clinical presentation

An OCD may not be recognized and therefore not adequately treated. The lack of recognition may be due to the fact that the symptoms resemble those of the previous trauma. The symptoms of a nondisplaced acute lesion often are masked by swelling and pain from the lateral ligament lesion. Swelling, limited range of motion, and pain on weight bearing may persist after the symptoms of the ligament injury have resolved. If the symptoms of deep ankle pain on weight bearing persist after 6 weeks, an OCD should be suspected.

The typical symptom of a chronic lesion is persistent or intermittent deep ankle pain during or after activity.[434] Reactive swelling or joint stiffness may be present. Most patients have normal range of motion without swelling or tenderness on palpation. Locking and catching may be present in the case of a displaced fragment. However, the absence of swelling, locking, or catching does not rule out the presence of an OCD.

The pain probably does not arise from the cartilage but from the innervated subchondral bone.[112,434] Patients usually feel deep ankle pain caused by the OCD. Increased intraosseous pressure has been reported as a cause of pain.[24,345] The nerve endings in the subchondral bone are the most probable cause of this pain.[263]

Imaging

Radiographs (weight-bearing anteroposterior mortise and lateral views) are the preferred initial investigation for a suspected OCD.[440] The sensitivity and specificity of the combination of medical history, physical examination and radiography are 59% and 91%, respectively.[440] An anteroposterior heel rise view with the ankle in a plantarflexed position may reveal a posteriorly located defect.[440] The radiographs may show an area of detached bone or radiolucency. Initially, the damage may be too small to be visualized on routine radiography. By repeating the imaging in a later stage, the abnormality sometimes becomes apparent.

Computed tomography (CT) and magnetic resonance imaging (MRI) allow multiplanar and 3-dimensional evaluation. The sensitivity and specificity of CT to detect an OCD are 0.81 and 0.99, respectively; those of MRI are 0.96 and 0.96.[440] In diagnosing a talar OCD, CT is as accurate as

MRI ($p = 0.33$).[440] CT is useful in determining the size, location, shape and degree of displacement of osteochondral fragments, and is therefore valuable in preoperative planning.[160,370,440,457] MRI offers the advantage of visualizing bone bruises, articular cartilage damage, and other soft tissue insults, but signal patterns in the talus may overestimate the severity of the bone injury.[303]

Treatment

Treatment options for OCDs are numerous. There is worldwide debate on the optimal strategy. In our clinic, several systematic reviews of the literature have been performed through the years.[393,439,458] The most recent update by Zengerink et al. included 52 studies with a total of 1361 patients.[458] The highest success rates were reported for bone marrow stimulation (85%) and osteochondral autograft transfer (87%). Because osteochondral autograft transfer can cause knee morbidity, the conclusion was that debridement and bone marrow stimulation remains the treatment of choice for primary OCDs (i.e., those without previous surgery) up to 15 mm.[458]

During debridement and bone marrow stimulation, the OCD is preferably approached by anterior ankle arthroscopy with the ankle in full plantar flexion for adequate exposure of the defect.[424] Most lesions of the anterior and central talar dome can be accessed with this technique. However, the ankle is a congruent joint with limited surgical access. Some defects are located so far posteriorly that they may not be accessible by anterior ankle arthroscopy. Alternatively, the OCD is exposed by posterior arthroscopy with the patient in the prone position or by open surgery. Whether the OCD can be reached by anterior ankle arthroscopy may often be unclear preoperatively. A predictive modality is required that preoperatively identifies the accessibility of the defect by the arthroscope. Moreover, quantification of normative data of the arthroscopic reach of the talus may be helpful for the planning of the surgical approach. Identifying predictive factors of the arthroscopic reach (e.g., patient characteristics and ankle function) may further improve the preoperative planning process.

Many studies report good to excellent short- and mid-term outcomes of debridement and bone marrow stimulation.[458] However, little is known about the long-term outcome. There are concerns that the fibrocartilage that is formed after this procedure may deteriorate over time, resulting in osteoarthritic changes.[262,303] Therefore, a long-term follow-up study is required.

The rehabilitation after debridement and bone marrow stimulation for symptomatic OCDs may take up to 1 year postoperatively. Many patients aim to achieve resumption of sport activities. A potential solution to accelerate postoperative rehabilitation and shorten the period to sport resumption is the application of pulsed electromagnetic fields (PEMFs). PEMFs have been shown to suppress inflammation, promote tissue healing, and relieve pain.[436] They have been used successfully in healing of nonunited fractures and in recovery after arthroscopic treatment of knee lesions.[161,441,462] However, the effectiveness of PEMFs for talar OCDs is unknown.

Lesions after failed previous surgery or large lesions can be treated by various alternative surgical methods, including autologous cancellous bone grafting, osteochondral autograft transfer, and (matrix-associated) autologous chondrocyte implantation.[457] Although successful results can be achieved, disadvantages of these secondary methods include pain at the donor site, limited availability of graft material, and two surgical procedures, i.e., one for harvesting the graft material and one for graft implantation.[224,299,312,357] An alternative without these disadvantages would be desirable.

A 15-mm metal resurfacing inlay implant was developed for secondary OCDs of the medial talar dome. The implant set consists of 15 offset sizes that are based on the geometry of the medial talar dome. The aim is to provide a matching implant for each patient. The implant possibly is a viable treatment option for secondary OCDs because it can be implanted in one session without the risk of donor-site morbidity. In theory, it should be implanted slightly recessed relative to the adjacent cartilage, in order to prevent excessive contact pressure by the implant on the opposite tibial joint surface. Before the implant can be used safely in patients, it is important to know whether the spectrum of offset sizes is adequate, whether the implantation level is reproducible, and whether excessive contact pressures at the opposing tibial plafond are avoided. After these items have been elucidated, the implant can be used in patients. Naturally, thorough follow-up of these patients is required to evaluate the clinical effectiveness.

An oblique medial malleolar osteotomy is a crucial step in the surgical implantation of the resurfacing inlay implant to provide perpendicular access to the medial talar dome. To obtain a congruent joint surface after refixation, the osteotomy should be directed perpendicularly to the articular surface of the tibia at the intersection between the tibial plafond and medial malleolus. At an instructional course on the metallic implantation technique, surgeons experienced technical difficulties performing a successful medial malleolar osteotomy. The difficulties included sawing at an angle that allowed refixation of the distal fragment without creating an articular incongruence, as well as identifying the intersection between the tibial plafond and medial malleolus. Thus, knowledge of the angle of the osteotomy relative to an anatomic landmark such as the long tibial axis would be helpful for use during surgery, as well as surgical tricks to identify the intersection.

As stated above, the main target in the treatment of talar OCDs is repair of the subchondral bone. Ideally, the surgery involves a one-step, minimally invasive procedure.[433] A healthy restored subchondral bone plate would decrease the pain, improve the load-bearing capacity of the ankle, and improve chondrocyte survival in the remaining cartilage.[16,263,434]

Demineralized bone matrix (DBM) from donors is a possible alternative to autologous bone grafting. It has been successfully used in the treatment of OCDs of rabbit knees.[140] DBM has been ascribed osteoconductive, osteoinductive, and osteogenic potential.[110,114,318] Osteoconduction is a property of a matrix that supports the attachment of bone-forming cells for subsequent bone formation.[97] Osteoinduction is a process that supports the mitogenesis of undifferentiated mesenchymal cells, leading to the formation of osteoprogenitor cells that form new bone.[97] Osteogenic property can be defined as the generation of bone from bone-forming cells.[97] Autologous platelet-rich plasma (PRP) contains concentrated growth factors, which may further improve the treatment effect of DBM. It is obtained by the centrifuge of venous blood. Neither the use of DBM nor PRP have been investigated in the treatment of talar OCDs.

Animal models are often essential in the testing of orthopaedic procedures prior to clinical use in humans. However, experimental animal studies of articular cartilage defects predominantly investigate the knee.[81] These knee studies cannot reliably be extrapolated to patients with ankle defects, because the knee and ankle have clearly different properties.[85,399] A large animal model specifically designed for the ankle would allow the investigation of DBM, PRP, and other alternatives before clinical application.

Outcome assessment

The reporting of outcome after treatment requires reliable and valid outcome scores. The score preferably should be translated and validated in the target population. A large amount of outcome measures have been used for evaluation of OCDs.[458] However, none of the outcome measures has been specifically designed or validated for OCDs. Because of the diversity of the outcome measures, comparison and pooling of studies may be unreliable. A clear guideline as well as the validation of existing outcome measures would enable more consistent reporting of outcomes.

Aims and outline of the thesis

This thesis investigates various aspects of talar OCDs that were introduced in the previous sections. Part I of the thesis describes the current concepts in the treatment of OCDs. Part II contains chapters on primary arthroscopic debridement and bone marrow stimulation. It aims to improve the preoperative planning of the arthroscopic approach, evaluate the long-term outcomes, and accelerate postoperative rehabilitation. Part III presents the biomechanical and clinical evaluation of a metal resurfacing inlay implant as a new secondary treatment method. It also aims to refine the medial malleolar osteotomy, which is used as a surgical approach to the talus. Part IV describes animal studies on an alternative treatment with DBM and PRP. Part V presents an overview and recommendations of outcome measures used for OCD treatment and the validation of the German Foot and Ankle Outcome Score. Part VI finalizes the thesis with a general discussion and a summary.

Part I – Current concepts

As described above, there are numerous management options and surgical strategies in the treatment of OCDs. **Chapter 2** aims to provide an overview of treatment options. Based on the literature, a treatment algorithm is proposed. **Chapter 3** describes the evolution and the various possibilities of anterior and posterior ankle arthroscopy.

Part II – Primary arthroscopic debridement and bone marrow stimulation

The optimal arthroscopic approach (i.e., anterior or posterior) can be unclear preoperatively. During anterior arthroscopic treatment of an OCD, the ankle is held in full plantar flexion to reach the defect.[424] The purpose of **chapter 4** is to determine whether preoperative CT of the ankle joint in full plantar flexion is a reliable and accurate tool to determine the anterior arthroscopic reach of talar OCDs. The dual purpose of **chapter 5** is (1) to quantify the anterior arthroscopic reach with the ankle in full plantar flexion in a larger group of patients using CT scans, and (2) to identify predictive factors of the arthroscopic reach.

Although arthroscopic debridement and bone marrow stimulation is recommended as the primary treatment, long-term outcome data are scarce. The primary aim of **chapter 6** is to assess the long-term clinical and radiographic outcomes of arthroscopic debridement and bone marrow stimulation for talar OCDs. The secondary aim is to identify prognostic factors that affect the long-term results.

Bone marrow stimulation can be achieved by drilling or microfracturing. **Chapter 7** identifies a potential pitfall in the arthroscopic microfracturing technique.

Early sport resumption after treatment in the young and active population remains a challenge. **Chapter 8** describes a detailed

study protocol of a randomized controlled trial, which investigates whether PEMF leads to earlier resumption of sports in a higher percentage of patients with an OCD of the talus after arthroscopic debridement and microfracturing.

Part III – Secondary surgical treatment with a metal resurfacing inlay implant

Because of the disadvantages of current secondary treatment methods, such as donor-site morbidity and limited availability, a metal resurfacing inlay implant was developed. **Chapter 9** aims to investigate whether the offset sizes are adequate for various cadaveric tali, whether the device can be reproducibly implanted slightly recessed relative to the adjacent cartilage, and, whether excessive contact pressures to the opposite cartilage can be avoided with this implantation level.

The goal of **chapter 10** is to evaluate the clinical safety and efficacy of the metal implant in patients with an OCD of the medial talar dome after failed previous treatment.

A medial malleolar osteotomy is indicated for the surgical implantation of the metal device. To obtain a congruent joint surface after refixation, the osteotomy should be directed perpendicularly to the articular surface of the tibia at the intersection between the tibial plafond and medial malleolus. The purpose of **chapter 11** is to determine this perpendicular direction in relation to the longitudinal tibial axis on radiographs for application during surgery. **Chapter 12** describes the use of a right-angled aiming probe to facilitate identification of the optimal terminal point of the medial malleolar osteotomy.

Part IV – Alternative treatment

In the absence of an animal model for the investigation of alternative treatment of talar OCDs, we have developed a caprine model for the ankle joint. The aim of **chapter 13** is to test the feasibility of the developed animal model in a small number of goats.

DBM and PRP possess properties that may enhance the repair of OCDs.[140,275] **Chapter 14** investigates whether DBM leads to more bone regeneration than control OCDs of the goat's talus, and whether PRP improves the effectiveness of DBM.

Part V – Outcome measures

Because a large amount of outcome measures are used in the literature for evaluation of OCDs, comparison of different studies may be unreliable. The objective of **chapter 15** is to describe and discuss frequently used clinical and functional outcome scores, as well as postoperative imaging modalities, and provide directions for use.

The study protocol of chapter 10 has been designed as a multicenter study in cooperation with a German university hospital. An important outcome score of the study is the Foot and Ankle Outcome Score (FAOS). A Dutch version has been translated and validated. To also evaluate the German patients reliably, the objective of **chapter 16** is to translate and validate a German version of the FAOS.

General discussion

Chapter 17 provides a general discussion and a summary of the thesis.

Part I
Current concepts

Chapter 2

Treatment of osteochondral defects of the talus

Christiaan J.A. van Bergen
Peter A.J. de Leeuw
C. Niek van Dijk

Revue de Chirurgie Orthopédique et Réparatrice de l'Appareil Moteur
2008;94(8 Suppl):635-646.

Abstract

This review article provides a current concepts overview of osteochondral defects of the talus, with special emphasis on treatment options, their indications and future developments. Osteochondral defects of the talar dome are mostly caused by a traumatic event. They may lead to deep ankle pain on weight bearing, prolonged swelling, diminished range of motion, and synovitis. Plain radiographs may disclose the lesion. For further diagnostic evaluation, computed tomography (CT) and magnetic resonance imaging have demonstrated similar accuracy. CT scanning is preferred for preoperative planning. Treatment options are diverse and up to the present there is no consensus. Based on the current literature, we present a treatment algorithm that is mainly guided by the size of the lesion. Asymptomatic or low-symptomatic lesions are treated nonoperatively. The primary surgical treatment of defects up to 15 mm in diameter consists of arthroscopic debridement and bone marrow stimulation. For large cystic talar lesions, retrograde drilling combined with a bone graft is an important alternative. In adolescents or in (sub)acute situations, in which the fragment is 15 mm or larger, fixation of the fragment is preferred. Osteochondral autograft transfer and autologous chondrocyte implantation, with or without a cancellous bone graft, are recommended for secondary cases as well as large lesions.

Introduction

An osteochondral defect (OCD) is the collective term for focal lesions involving the articular cartilage and subchondral bone. If only cartilage is involved in the pathology, the term chondral defect is used. Many synonyms are used, including osteochondritis dissecans,[135] transchondral fracture,[49] flake fracture,[197] talar dome fracture,[30] osteochondral fracture,[19] osteochondral lesion,[235] and osteochondral defect.[346] A differentiation should be made between traumatic and nontraumatic origin (i.e., osteochondritis dissecans). A traumatic event may lead to (partial) detachment of an (osteo)chondral fragment, which may further evolve in the formation of a subchondral cyst with or without osteonecrosis. There is sometimes confusion between traumatic and nontraumatic, because a nontraumatic OCD may become symptomatic after trauma.

In 1856, Monro first reported the presence of cartilaginous bodies.[290] In 1888, König used the term osteochondritis dissecans for loose body formation associated with articular cartilage and subchondral bone fracture.[227] He referred to an inflammatory process, although this has never been proved to be involved in the pathology. It was not until 1922 that the first report on osteochondritis dissecans in the ankle was published.[206] The talar dome is the secondly most common location in the human body; most occur in the knee.[457]

An OCD is often not recognized and therefore not adequately treated. The nonrecognition is mainly due to the fact that the lesion produces symptoms of previous trauma, and it cannot always be identified on plain radiographs.[440] After standard treatment for acute ankle sprains, residual symptoms are reported in 33% of patients.[56] In these cases, the possibility of an OCD should be considered.

The talus has a limited reparative capacity because of its restricted vascular supply.[344] Inappropriate treatment of OCDs may result in chronic ankle pain, functional impairment, subchondral cyst formation, and eventually osteoarthritis of the ankle.[69,268,344]

For the last decade, great developments have been made in the surgical treatment. Despite advancements in options like osteochondral autograft transfer system (OATS) or autologous chondrocyte implantation (ACI), arthroscopic debridement and bone marrow stimulation remains the best treatment that is currently available for defects up to 15 mm in diameter.[393,439] In larger (cystic) defects this treatment is less successful, and hence there is more debate.[82,149]

The aim of this article is to provide an overview of treatment options and their indications for OCDs of the talus, based on the current evidence.

Etiology

In 1985, trauma was described in 98% of lateral lesions and in 70% of medial lesions.[135] More recently, 93% was reported for lateral lesions and 61% for medial lesions.[439] As not all patients report a history of ankle injury, a subdivision can be made in the etiology of nontraumatic and traumatic defects.

Ischemia, subsequent necrosis, and possibly genetics are etiologic factors in nontraumatic OCDs.[344] Furthermore, OCDs in identical twins and in siblings have been described.[18,455] Less reported possible causes are metabolic, vascular, endocrine, and degenerative factors, as well as morphologic abnormalities.[49,63,457]

In the etiology of traumatic OCDs, ankle sprains play the largest role. A severe ankle sprain may cause a small fracture and subsequent impaired vascularity, leading to the formation of an OCD. Alternatively, the cause may not be a single event but may consist of a series of repeated, less intense injuries.[63,344] Microtraumas caused by repetitive surface loading or excessive stress can lead to cartilage cellular degeneration or apoptosis and thickening of the subchondral bone.[137]

Mechanism of injury

During an ankle sprain, the talus twists inside the ankle mortise, which may lead to a bruise and subsequent softening or even delamination of the cartilage. Separation may occur in the upper layer, as a result of shearing forces, or may occur in the subchondral bone. Osteocartilaginous fragments either remain partially attached or become loose bodies in the ankle joint. The subchondral fracture has no soft-tissue attachments and is highly susceptible to subsequent avascular necrosis.[457] The repetitive forcing of synovial fluid into the underlying cancellous bone with every step of walking may create a subchondral cyst.[349] The repetitive fluid pressure may prevent healing of a subchondral cyst.

Berndt and Harty clearly described the trauma mechanism in cadaver ankles.[49] They were able to reproduce lateral defects by strong inversion of a dorsiflexed ankle, leading to compression of the lateral border of the talar dome against the face of the fibula. Partial detachment of the chip occurred when the lateral ligament ruptured. They reproduced medial lesions by plantar flexion and inversion of the ankle combined with slight anterior displacement and lateral rotation of the tibia upon the talus.

The lateral lesions are typically shallow and wafer-shaped, indicating the shear mechanism of injury.[69] Because of their shape, lateral lesions are more frequently displaced than medial lesions. In contrast, medial lesions are generally deep and cup-shaped, indicating a mechanism of torsional impaction.[69] Medial lesions are usually larger than lateral lesions.[322]

Epidemiology

With the increased awareness and newer diagnostic techniques, the incidence of OCD seems to increase.[257] In 1955, Bosien et al described an

incidence of 7% in 113 patients conservatively treated for acute lateral ankle ligament ruptures.[56] Later, van Dijk et al. reported 4% fresh talar dome lesions and 67% fresh chondral lesions of any kind in 30 patients who had operative repair of acute ruptures of lateral ligaments.[422] More recently, an even higher incidence was reported, namely 41% of 86 patients with anterior talofibular ligament disruptions and 71% of 92 patients with distal fibular fractures.[376] However, the majority of these reported lesions were located at the cartilage covering the anterior aspect of the medial malleolus and the opposite medial talar facet or the anteromedial rim of the tibial plafond.[376,422] Accordingly, talar OCDs were found in 28% to 40% of patients with ankle fractures treated by arthroscopically assisted open reduction and internal fixation.[11,259] In these series, the highest incidence was found in patients with distal fibular fractures.[11,259]

Most OCDs are localized on the posteromedial (58%) or anterolateral (42%) talar dome (Figure 1), although anteromedial, posterolateral and central lesions also occur.[322,439] In a large magnetic resonance imaging (MRI) survey of 428 affected ankles, 53% of the lesions were localized centromedially and 26% centrolaterally.[322]

In 4% to 7% of patients, the occurrence of the defect is bilateral,[49,69,235] suggesting nontraumatic osteochondritis dissecans. Patients with an OCD are frequently 20- to 30-year-old men.[49,393,439]

Clinical presentation

An OCD often causes deep pain, swelling, recurrent synovitis, and sometimes locking complaints. A differentiation has to be made between the acute and chronic situation.[457] In the acute situation, symptoms of the OCD compare to those of acute ankle injuries, including lateral or medial ankle pain, swelling, and limited range of motion. In patients with an isolated ligamentous ankle injury, these symptoms usually resolve after functional treatment within 2 to 3 weeks. If symptoms do not resolve after 3 to 6 weeks, an OCD should be suspected. These patients usually present with persisting symptoms and sometimes a limited range of motion. Locking and catching are symptoms of a displaced fragment. In most patients with a nondisplaced lesion, the symptoms in the acute situation cannot be distinguished from the soft tissue damage.

Chronic lesions typically present as persistent or intermittent deep ankle pain, during or after activity. Reactive swelling and stiffness may be present, but absence of swelling, locking, or catching does not rule out an OCD. There may be a normal range of motion, with the absence of swelling and absence of recognizable tenderness on palpation.

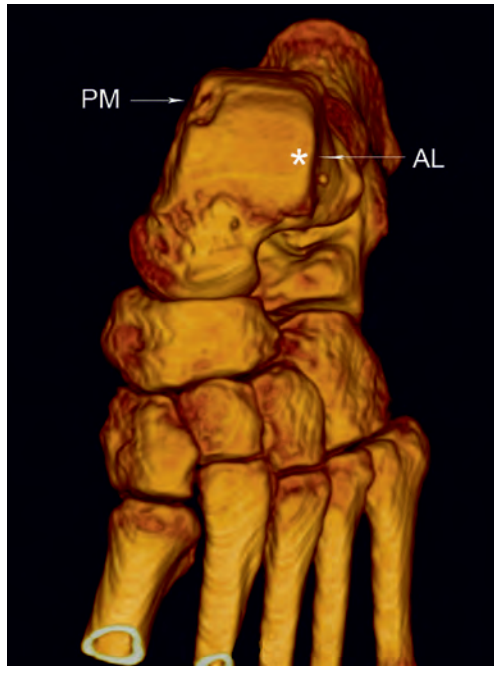

Figure 1. Three-dimensional CT reconstruction of the left ankle of a 26-year-old male patient with a large osteochondral defect typically localized on the posteromedial (PM) talar dome. The usual localization of an anterolateral (AL) defect is also indicated (*).

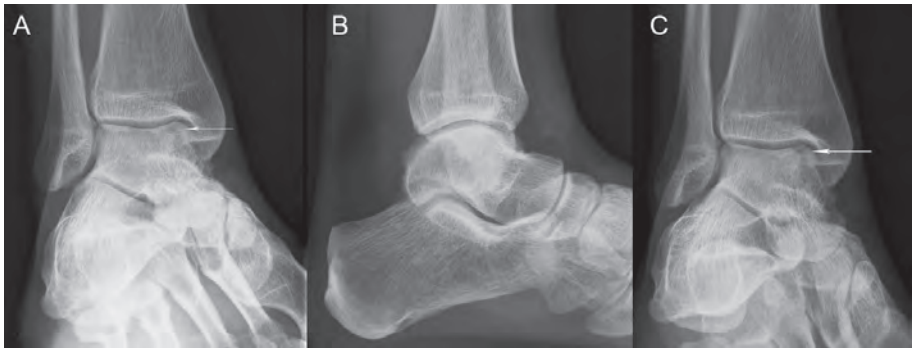

Figure 2. Weight-bearing anteroposterior (A) and lateral (B) radiographs of the right ankle of a 36-year-old male patient showing radiolucency in the medial talar dome (arrow), indicating an osteochondral defect. A 4-cm heel rise view (C) of the same ankle reveals the posteromedial osteochondral defect more clearly (arrow).

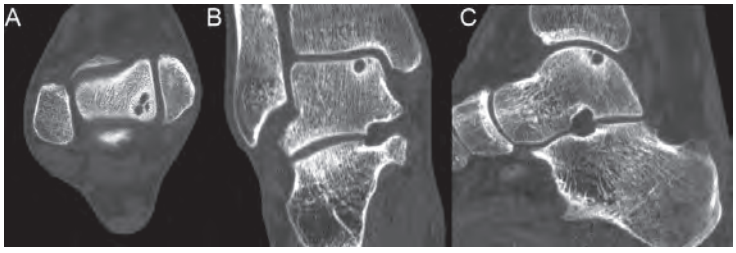

Figure 3. CT scans of the right ankle of a 26-year-old female patient showing a cystic posteromedial osteochondral ankle defect. (A) Axial slice, (B) Coronal reconstruction, (C) Sagittal reconstruction.

Diagnosis

Routine radiographs of the ankle should be obtained after careful history taking and physical examination of the ankle. These consist of weight-bearing anteroposterior (mortise) and lateral views of both ankles. The sensitivity and specificity of the combination of medical history, physical examination, and radiography are 59% and 91%, respectively.[440] The radiographs may not reveal any pathology, or show an area of radiolucency Figure (2A). Initially, the damage may be too small to be visualized on a routine X-ray. The OCD sometimes becomes apparent on radiographs at a later stage. A posteromedial or posterolateral defect may be revealed by a heel rise mortise view with the ankle in plantar flexion (Figure 2C).[440]

For further diagnostic evaluation MRI or computed tomography (CT) are often used, with similar accuracy.[440] A multislice helical CT scan is useful for defining the exact size and location of the lesion, and is therefore preferred for preoperative planning (Figure 3).[370,457] The scanning protocol involves "ultra high resolution" axial slices with an increment of 0.3 mm and a thickness of 0.6 mm. Multiplanar coronal and sagittal reconstructions should be 1 mm.

Classification

A number of classifications have been proposed, based on radiography, CT, MRI, and arthroscopy.[19,49,182,257,376,381] The first and most frequently used classification is from Berndt and Harty:[49]

Stage I A small compression fracture
Stage II Incomplete avulsion of a fragment
Stage III Complete avulsion of a fragment without displacement
Stage IV Displaced fragment

Scranton and McDermott later added Stage V, representing cystic lesions.[349]

CT scans are increasingly used in the preoperative workup. A CT classification was therefore introduced in 1993, resembling the above classification, with stage V representing a radiolucent defect.[257] None of the current grading systems, however, is sufficient to direct the choice of treatment.

Treatment

Various surgical techniques for symptomatic OCDs have been published. These are generally based on one of the following three principles:[457]

- Debridement and bone marrow stimulation (microfracturing, drilling, abrasion arthroplasty), with or without loose body removal;
- Securing a lesion to the talar dome (fragment fixation, retrograde drilling, cancellous bone grafting);
- Development or replacement of hyaline cartilage (osteochondral autograft transfer, autologous chondrocyte implantation, allografts).

For years there has been an ongoing debate about the optimal treatment regime. Debridement of the lesion has been performed progressively since the 1950s.[49] This method was later combined with bone marrow stimulation, by means of drilling or microfracturing, with favorable results.[12] With the development of ankle arthroscopy, this combined procedure gained much popularity.[235,346,424] Nowadays, arthroscopic debridement and bone marrow stimulation is the mostly performed procedure for OCD. Publications on treatment options for talar OCDs were bundled in a systematic review, performed in our institution in July 1998, and updated in June 2000.[393,439] Twenty-one investigations with a total of 272 patients were identified. The success rate of debridement and bone marrow stimulation was superior to other methods. Arthroscopy was successful in 87% and open procedures in 84% of the cases.[439] These good results were confirmed more recently.[179,343] However, osteochondral autograft transfer system (OATS) and autologous chondrocyte implantation (ACI) were not included due to few studies, and sizes of the treated lesions were not described.

In the case of a cystic lesion, debridement may be supplemented by cancellous bone grafting.[224,343,457] However, the limited availability of cancellous bone and pain at the donor site remain disadvantages.[357] Large osteochondral fragments can be fixed by screws, with a success rate of 73% (Figure 4).[393]

Recently, more developments have taken place. OATS and ACI as original procedures for osteochondral lesions of the knee have evolved to suitable treatment methods for certain lesions of the talus.[61,177,315] Excellent results have been published, although numbers are still fairly small and no long-term follow-up is available.[39,40,176,315]

In 2005, an expert consensus on the treatment of OCD was achieved during the World Consensus Conference of the International Society of Arthroscopy, Knee surgery & Orthopaedic Sports medicine and International Federation of Sports Medicine (ISAKOS-FIMS).[429] The expert group agreed that debridement and bone marrow stimulation is the first step in the treatment of most symptomatic OCDs, and presented a useful guideline. For failed primary treatment they recommended to consider OATS.

Based on the current literature, a revised treatment guideline is presented (Table 1), which will be further discussed in the Discussion section.

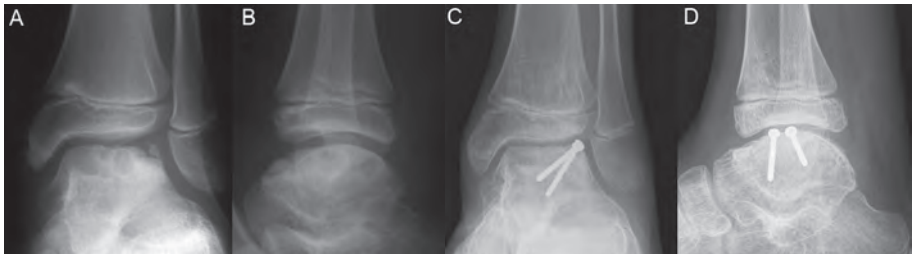

Figure 4. Weight-bearing radiographs of the left ankle of a 13-year-old male patient with progressive complaints of deep ankle pain over 18 months without preceding trauma. Preoperative anteroposterior (A) and lateral (B) radiographs show a large lateral radiolucent area involving more than 50% of the talar dome, representing partial talar necrosis. The lesion was secured to the talus by means of two compression screws. The radiographs (C) and (D) represent the situation 6 months postoperatively in which the lesion was healed. Screw removal was performed 3 months later.

Table 1. Guideline for treatment of osteochondral defects of the talus

Lesion type	Treatment options
Asymptomatic or low-symptomatic	Conservative
Symptomatic, <15 mm	Conservativea, debridement and drilling/microfracturing
Symptomatic, ≥15 mm	Fragment fixation, OATS, ACI, debridement and drilling/microfracturing
Cystic, ≥15 mm	Debridement +/- (retrograde) drilling/microfracturing with cancellous bone, OATS, ACI with cancellous bone
Secondary	OATS, ACI, HemiCAP®b, TruFit®b
Massive lesion	Allograft, ankle arthrodesis, total ankle replacement

ACI = autologous chondrocyte implantation and OATS = osteochondral autograft transfer system.
[a] A trial period of six months conservative treatment is recommended.
[b] Resurfacing of the medial talar dome by a metal implant (HemiCAP®) and a biodegradable double-layer implant (TruFit®) might become valuable alternatives in the future.

Surgical approach

The size and location of the lesion as well as the type of surgical treatment determine the surgical approach. The preferred approach of most lesions is by means of anterior arthroscopy.[432] Alternative approaches are posterior arthroscopy by means of a two-portal hindfoot approach and open arthrotomy with or without a medial malleolar osteotomy.[200,281,427] Arthroscopy offers the advantages of outpatient treatment and possibly less postoperative morbidity, faster and functional rehabilitation, and earlier resumption of sports [432]. Lateral lesions seldom require a malleolar osteotomy. In the rare case of a posteriorly localized lateral lesion, a fibular osteotomy provides the best open exposure.[142]

In the situation of debridement and bone marrow stimulation, the majority of lesions can be treated by means of anterior arthroscopy with the ankle in full plantar flexion. As a rule of thumb, lesions located in the anterior half or in the anterior part of the posterior half of the talus in patients with unlimited plantar flexion can be reached and treated this way.[432] Some ligament laxity will improve the exposure.

Debridement and bone marrow stimulation

With this technique, all unstable cartilage is removed, including the underlying necrotic bone. Any cysts underlying the defect are opened and curetted. After debridement, several connections with the subchondral bone are created by drilling or microfracturing. The objective is to partially destroy the calcified zone that is often present and to create openings into the subchondral bone. Intraosseous blood vessels are disrupted and the release of growth factors leads to the formation of a fibrin clot. The formation of local new blood vessels is stimulated, marrow cells are introduced in the defect, and fibrocartilaginous tissue is formed.[301]

Advantages of this technique are the possibility of arthroscopy, the relatively easy procedure, and early rehabilitation. A disadvantage is the formation of fibrous cartilage rather than hyaline cartilage. Although often successful, this may be insufficient for large defects.[82]

Preoperatively, the approach to the defect should be determined (see Surgical approach section). In the case of arthroscopic treatment it has to be decided whether to use a 4.0-mm arthroscope and treat the OCD in the anterior working area by full plantar flexion of the ankle, or to use a 2.7-mm arthroscope in combination with mechanical distraction.[424] Arthroscopy with the foot in full plantar flexion is the preferred method in most cases, although skill and experience are required.[346,432]

The subchondral bone can be perforated using a 2-mm drill, a microfracture awl or a 1.4-mm Kirscher wire (K-wire). A K-wire has the advantage of flexibility, whereas a drill may break more easily if the position of the ankle is changed during drilling. Microfracturing by means of a microfracture awl offers the possibility to work "around the corner" and results in microfractures of the trabeculae rather than destruction of the bone,[368] but any created small bony particles should be carefully removed.[409]

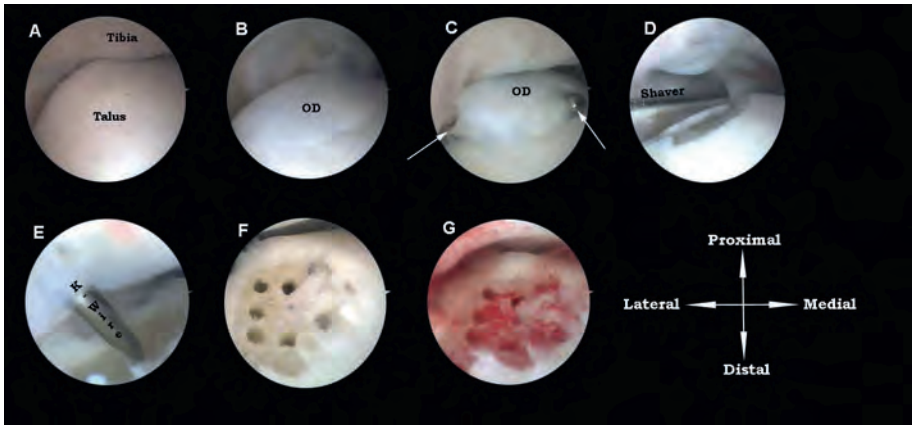

Figure 5. Arthroscopic images of the right talus of a 17-year-old female patient with a lateral osteochondral defect (OD) that is treated by debridement and drilling. The arthroscope is in the anteromedial portal (A). With the ankle in the neutral position the defect is out of the arthroscopic view. By bringing the ankle in plantar flexion the defect can be seen (B). The size of the lesion is identified by palpating the cartilage with a probe (arrows), which is inserted through the anterolateral portal (C). A shaver is introduced for debridement of the defect (D). With use of a K-wire small holes are drilled in the subchondral bone (E). Arthroscopic view of the treated lesion after switching portals (F). During loosening of the tourniquet sufficient hemorrhage in the defect is checked (G).

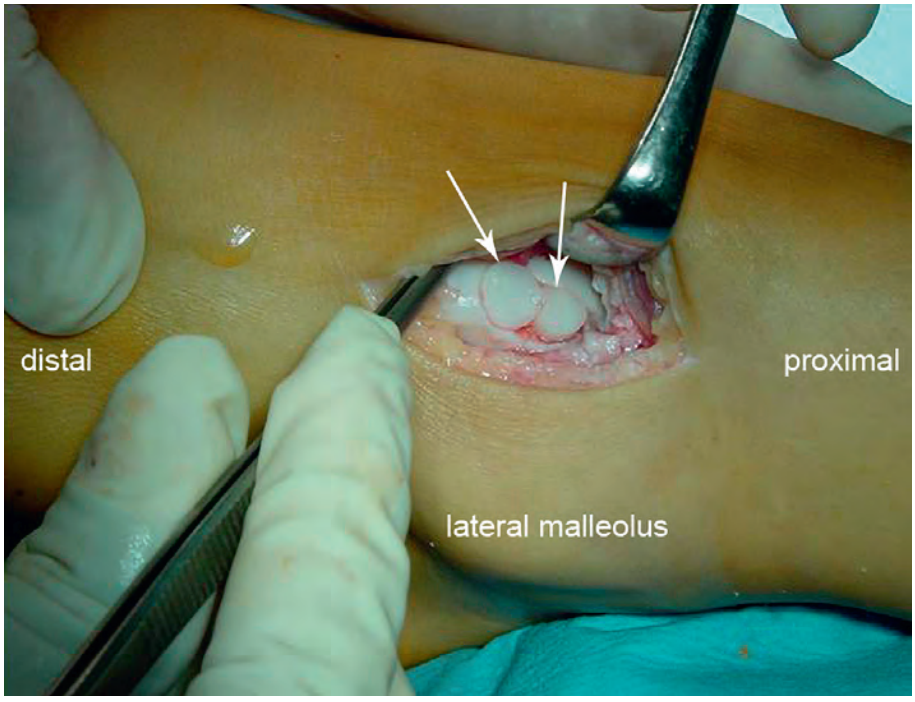

Figure 6. Osteochondral defect of the anterolateral talar dome after treatment with two osteochondral autografts (arrows), measuring 6.5 and 4.5 mm in diameter, harvested from the knee.

Operative technique

The standard anteromedial and anterolateral approaches are created in the fully dorsiflexed position, as described previously.[424,432] Introduction of the 4.0-mm arthroscope and a 4.5- or 5.5-mm bonecutter shaver is performed with the ankle in the fully dorsiflexed position to prevent iatrogenic cartilage damage. If osteophytes or synovitis are present, they are removed first by a chisel, burr, or bonecutter shaver, with the ankle in the dorsiflexed position. The completeness of removal is checked by plantarflexing the ankle. During this part of the procedure a soft tissue distractor may be applied (Figure 5A).[424,428] It should now be possible to visualise the lesion in the forced plantarflexed position (Figure 5B) and to identify the defect by palpating the cartilage with a probe or hook (Figure 5C). Debridement is performed with use of the bonecutter shaver or a small closed-cup curette (Figure 5D). It is important to remove all necrotic bone and overlying unstable cartilage.[378] After full debridement, the sclerotic zone is perforated several times at intervals of approximately 3 mm (Figures 5E and F). Sufficient hemorrhage can be checked by loosening of the tourniquet (Figure 5G).

Rehabilitation

Active plantar flexion and dorsiflexion are encouraged. Partial weight bearing (eggshell) is allowed as tolerated. It is the senior author's practice to allow progress to full weight bearing within 2 to 4 weeks in patients with central or posterior lesions of up to 1 cm. Larger lesions and anterior lesions require partial weight bearing up to 6 weeks. Running on even ground is permitted after 12 weeks.[457] Sport is resumed after an average of 15.1 weeks.[343] Full return to

normal and sporting activities is usually possible 4 to 6 months after surgery.[82]

Osteochondral autograft transfer

OATS consists of the harvesting of one or more osteochondral plugs in a lesser—weight-bearing area of the knee and transplanting them into the talar defect.[177,350] The aim is to restore the articular surface with hyaline cartilage. One single graft or several smaller grafts (i.e., mosaicplasty) may be used. The use of several grafts provides a better match to the curvature of the talar dome and surface area of the defect, and may reduce donor site morbidity.[78,176]

Although X-ray evaluation and CT may help to determine the extent of the lesion, indication of OATS is rather based on the size determined after excision of the defect. OATS can also be offered to patients in case of failed primary treatment (see Table 1). An essential aspect of the procedure is insertion of the osteochondral plugs perpendicular to the recipient site. Due to the constrained configuration of the talocrural joint with its highly contoured articular surfaces, the best approach is by means of open arthrotomy, most of the times using a malleolar osteotomy. The primary harvest site is the medial upper part of the medial femoral condyle. As a less frequent option, the lateral supracondylar ridge can also be used through a miniarthrotomy.[457] In case the knee is precludes as a donor site, the ipsilateral talar articular facet may also be used as a harvest site of small sized grafts (2.7 or 3.5 mm in diameter).[231]

Operative technique

For medial lesions a medial malleolar osteotomy is usually required. Once the lesion is exposed, all diseased and suspect cartilage is removed by curette and scalpel dissection to a sharply defined rim. After debridement of the bony base of the defect by curettage or abrasion arthroplasty, the sharp cutting edge of the appropriate-size drill guide helps to determine an ideal filling rate of the defect. The usual size of the drill holes in the talus is 4.5 or 6.5 mm in diameter (Figure 6).

Upon completion of the recipient site preparation, osteochondral grafts are harvested from the ipsilateral knee. Once the site has been clearly identified, the proper size tubular chisel is directed perpendicularly to the articular surface and driven by a hammer to the appropriate depth. Minimal graft length should be at least twice its diameter.[457] Three to four plugs can be obtained by flexing the knee from 0° to 100°. At the end of the graft harvesting a suction drain is left behind in the knee joint.

After the graft harvest the recipient site is again evaluated. The first hole is drilled through the tubular drill guide, which also serves as the delivery tube. The depth should be 3 – 4 mm deeper than the length of the selected plug. At this stage the hole is enlarged by 0.1 – 0.2 mm with use of a conical dilator, allowing easy insertion of the graft. For each graft, drilling, dilation, and delivery are done as a combined step accordingly. After the entire set of grafts is implanted (see Figure 6), the ankle is lavaged, observed for loose bodies, and sent through a range of motion to ensure congruency of the mosaicplasty. The osteotomy site is reduced and internal fixation is performed utilizing the predrilled screw holes.

Rehabilitation

Patients are kept non-weight bearing for 3 weeks; 6 weeks for those with a malleolar osteotomy. Following this period, partial weight bearing up to 30 kg for 3 weeks is allowed to promote integration of the grafts. An orthosis may improve comfort. Range-of-motion exercises are encouraged. Unprotected weight bearing is subsequently allowed. Athletic activities may begin at approximately 6 months.

Autologous chondrocyte implantation

ACI is the implantation of in vitro cultured autologous chondrocytes using a periosteal tissue cover after expansion of isolated chondrocytes. ACI has been popularized by Brittberg and Peterson since 1994.[61,315] Since that time, ACI has been performed in over 25,000 patients; 95% in the knee, 3% in the ankle, and 2% in other joints.[457] Based on promising early results with ACI in the knee, surgeons have now started using ACI for osteochondral lesions of the talus.

For patients with an OCD who remain symptomatic after primary surgical treatment ACI is considered a valuable treatment option. The defect should be focal, contained, and preferably more than 1.5 cm in diameter. Large lesions with subchondral cysts may also be treated with ACI, using the "sandwich technique", i.e., filling the base of the defect with autologous cancellous bone.[40,315]

Contraindications to ACI are bipolar lesions ("kissing lesions") and diffuse degenerative joint changes. Skeletal malalignment and ligamentous instability are also contraindications, unless they are concomitantly corrected at the time of surgery.[40]

Operative technique

ACI is a staged procedure. The initial surgery consists of ipsilateral knee arthroscopy for cartilage harvesting. Articular cartilage is harvested from non—weight-bearing surfaces such as the intercondylar notch. Approximately 200 – 300 mg of cartilage is harvested with use of curettes and sent to the laboratory for chondrocyte isolation and proliferation.

The second stage of the procedure is usually at least 4 weeks after the harvesting procedure. A medial or lateral malleolar osteotomy is necessary to provide access for the ACI procedure.[40] All pathologic fibrous and cartilaginous tissue is debrided. One should not penetrate the subchondral bone during this step, as this would enable marrow elements to contaminate the cultured chondrocyte population.

The periosteal graft, oversized by 1 – 2 mm, is next obtained from the ipsilateral proximal or distal tibia. With the cambium side facing toward bone, the periosteal graft is placed over the defect and sutured with multifilament absorbable sutures, size 5.0 or 6.0. Fibrin glue is placed at the interface to help seal the graft. A small opening at the interface is left patent. Saline is injected, to confirm a watertight compartment, and subsequently aspirated from the defect. The cultured chondrocytes are then placed into the defect and the insertion site is closed with the last stitch and fibrin glue. The osteotomy is repaired with two malleolar screws inserted through predrilled holes.

Rehabilitation

The patient is kept non-weight bearing and placed in a well-padded short leg cast during the immediate postoperative period. At 2 weeks postoperatively, the patient is placed in a controlled action motion (CAM) walker boot. Partial weight bearing and gentle ankle range-of-motion exercises are permitted. Weight bearing is advanced based on radiographic evidence of osteotomy healing. At 6 weeks, the patient discontinues the use of the CAM walker. Repetitive impact activities, such as jogging and aerobics, can be resumed after 6 to 8 months. Return to high level sports is permitted after 12 months.

Future developments

To overcome the disadvantages of current treatment options various attempts are undertaken, aimed at the improvement of current techniques or the development of alternative methods.

To improve ACI, researchers are experimenting with alternatives. The detached osteochondral fragment has been proposed as a source of osteocytes to result in less morbidity.[148] Furthermore, different scaffolds have been developed that can be implanted with cultured chondrocytes, obviating the need for periosteal grafting for fixation.[75,269,451] Matrix-induced autologous chondrocyte implantation (MACI) makes use of a collagen type I-III membrane, which serves as the scaffold for implanted chondrocytes. Although this is promising in animal and human knees,[35,451] only two short-term ankle cases have been reported.[75] Using Hyalograft C as the scaffold, Giannini et al. performed arthroscopic ACI in 30 patients with good short-term results.[149]

Regarding OATS, the postoperative application of pulsed electromagnetic fields has been recently shown to limit graft resorption and cyst formation in sheep.[47]

As a tissue-engineering technique of cartilage, bone marrow-derived mesenchymal stem cells have been successfully implanted using different scaffolds. The majority of this research, however, is still experimental.[187,209,252,352] Jancewicz et al. were the first to report a clinical series in the talus.[199] Demineralized bone matrix has been proposed as an alternative to autologous bone grafts for the treatment of OCD.[140]

Experimental progress is made with the use of biodegradable composite implants. Müller et al. reported the use of double-layer biodegradable implants consisting of poly-dl-lactide and a polyglactin/polydioxanon fleece.[294] Jiang et al. investigated repair with a biphasic osteochondral composite consisting of b-tricalcium phosphate and dl-polylactide-co-glycolide seeded with autologous chondrocytes using single-stage surgery.[201] Commercially available composite implants have become available for the treatment of OCDs of the knee (TruFit Plug®, Smith & Nephew, San Antonio, TX, USA).[452]

Our research group is currently investigating the applicability of a novel resurfacing technique of the medial talar dome by means of a contoured metal implant (HemiCAP®, Arthrosurface Inc., Franklin, MA, USA).

Alignment and potential correction osteotomy are important issues. In case of persistent complaints after initial treatment, check the overall alignment and hindfoot alignment. The future role of correction osteotomy in the treatment algorithm of OCD has to be established.

Discussion

The choice of treatment depends on several factors, such as the patient's age, symptoms, duration of complaints, location and size of the defect, and whether it concerns a primary or secondary OCD.[82,149,235,457]

Asymptomatic or low-symptomatic lesions are treated nonoperatively by rest, ice, temporarily reduced weight bearing, and an orthosis in case of giving way, for a trial period of 6 months.[346,457] Although nonoperative therapy yields only 45% successful results,[439] a trial period does not adversely affect the outcome of surgery.[12] Cartilage lesions have demonstrated to deteriorate slowly in the ankle joint. Hence, the advice is to be conservative; there is always time to test the effect of debridement and bone marrow bone stimulation.

Surgical treatment is considered in the case of failure of nonoperative treatment or continuing symptoms after previous surgery (secondary OCD). According to reviews of the literature, the best currently available treatment for primary OCDs is the combination of excision, debridement, and bone marrow stimulation.[393,439] According to the ISAKOS – FIMS consensus, debridement and drilling or microfracturing is the first step in the treatment of symptomatic osteochondral lesions that are too

small to consider fixation.[429] Hence, symptomatic lesions up to 15 mm are treated primarily by debridement and bone marrow stimulation. Subchondral cystic lesions smaller than 15 mm do not influence the postoperative prognosis.[174]

In the case of a (cystic) defect sized 15 mm or larger, this technique might also be considered as a primary treatment option. In these cases, a cancellous bone graft may be placed in the defect after debridement.[109,149,343] Retrograde drilling, combined with cancellous bone grafting if necessary, may be performed if there is a (large) subchondral cyst with intact cartilage.[228,381] Alternatively, the cancellous bone graft may be placed underneath the cartilage flap after debridement of the subchondral bone.[109] A cancellous bone graft is harvested from the ipsilateral iliac crest or locally from the distal tibial metaphysic.[224] Possible drawbacks of this procedure are the limited availability and pain at the donor site.[357]

Fragment fixation with one or two screws or K-wires is preferred in (sub)acute situations in which the fragment is 15 mm or larger. In adolescents, fixation of an OCD should always be considered in case of failure of a period of conservative treatment (see Figure 4).[370]

In case of failed primary surgical treatment, OATS and the more recently introduced ACI are reasonable options.[23,39,176,177,315] They both aim at creating a new layer of hyaline cartilage.

OATS was originally developed to treat osteochondral lesions in the knee.[175] After promising early experiences, the indication was extended to the talus.[176] Christel et al. emphasized the difficulty of restoring the curvature of the articular surface and reported less favorable clinical outcome in the ankle than in the knee,[79] whereas other authors published promising results.[23,31,144,176]

Although hyaline cartilage of the donor area located in the knee is different from the talar hyaline cartilage, there is no evidence this would represent a negative influence on the results. However, the integration of donor and recipient hyaline cartilage can be impaired because of different mechanical properties and thickness.[79,147,241] Other possible disadvantages are the limited availability of grafts and the risk of donor site morbidity.[147,327] Furthermore, the use of a medial malleolar osteotomy to approach the lesion has been associated with a worse outcome, i.e., local osteoarthritis and higher morbidity[143] A randomized controlled trial with 2 years of follow-up comparing OATS with debridement (with or without microfracture) showed similar results among the methods.[156] However, the debridement and microfracture techniques were recommended because of less postoperative pain. Possible alternatives including artificial osteochondral plugs and metal implants may be used in the future.

The newer ACI offers a promising treatment alternative, but long-term data are lacking. Several authors have reported favorable results at short-term follow-up.[39,146,229,315,448,457] However, long-term studies are needed to evaluate the efficacy of this technique. Incomplete healing of subchondral cysts has been noted in some patients after ACI, although this did not adversely influence clinical outcomes at short-term follow-up.[457] Other possible disadvantages are insufficient graft integration, two-stage surgery and high costs.[71,147,448] Until further data are available, we cannot advocate ACI as an initial treatment option for most cases of OCD. However, in patients who have a large OCD or failed prior surgical treatment, the short-term data suggest that ACI can provide good results.

For massive OCDs, the transplantation of fresh or frozen allografts has been described. A number of experts have expressed their concerns of use in the talus, based upon the gradual deterioration of the hyaline part of such grafts in the knee and resorption and fragmentation of the graft.[162] Therefore, transplantation of osteochondral allografts is only indicated for massive

osteochondral lesions.[321] Salvage procedures for massive OCDs or recurrent failure of treatment are ankle arthrodesis or total ankle replacement.

Conclusion

The choice of treatment is hindered by the fact that none of the grading systems is related to current treatment options. In table 1 we present a guideline for treatment that is primarily based on the size of the lesion.

Arthroscopic debridement and bone marrow stimulation, by nature of the minimally invasive approach, has great advantage in treating typical defects of up to 1.5 cm in diameter. For larger OCDs, the optimal treatment may consist of OATS, cancellous bone graft, and/or ACI. The medium-term encouraging results of OATS and cancellous bone grafts hold promise for these procedures in lasting relief of symptoms and prevention of ankle osteoarthritis. ACI has encouraging short-term results in the ankle joint. Much research is performed to improve this method, and its place in the treatment algorithm remains to be further defined. Tissue-engineering techniques, artificial plugs, and resurfacing by metal implants might become reasonable alternatives in the future.

Chapter 3

Advancements in ankle arthroscopy

C. Niek van Dijk
Christiaan J.A. van Bergen

Journal of the American Academy of Orthopaedic Surgeons
2008;16(11):635-646.

Abstract

Important progress has been made during the past 30 years in arthroscopic ankle surgery. Ankle arthroscopy has gradually changed from a diagnostic to a therapeutic tool. Most arthroscopic procedures can be performed by using the anterior working area with the ankle in dorsiflexion or plantar flexion; there is no need for routine ankle distraction. Anterior ankle problems, such as the anterior impingement syndrome, are approached by anteromedial and anterolateral portals and, if necessary, an accessory portal. Most osteochondral defects can be reached from anterior with the ankle in plantar flexion. For a far posterior location, the osteochondral defect can be approached from posterior. The two-portal hindfoot endoscopic technique (i.e., both arthroscopoic and endoscopic surgery), with the patient in the prone position, provides excellent access to the posterior ankle compartment and to posteriorly located extra-articular structures.

Introduction

Although Burman in 1931 found the ankle joint unsuitable for arthroscopy because of its typical anatomy,[66] Tagaki and, later, Watanabe made considerable contributions to arthroscopic surgery.[374,446] Watanabe in 1972 published the results of a series of 28 ankle arthroscopies.[446] Numerous publications followed, and during the past 30 years, arthroscopy of the ankle joint has become an important procedure for the detection and treatment of chronic and posttraumatic problems. The main indications for anterior arthroscopy are for treatment of anterior impingement syndrome and talar osteochondral defects (OCDs).[126,424]

Endoscopic surgery (i.e., both arthroscopic and endoscopic surgery) offers the possible advantages of direct visualization of structures, improved assessment of articular cartilage, less postoperative morbidity, faster as well as functional rehabilitation, earlier resumption of sports, and outpatient treatment.[93,348] The value of diagnostic arthroscopy is limited.[424,425] Some authors advocate routine mechanical distraction combined with a 2.7-mm arthroscope.[59] In most procedures, however, ankle arthroscopy can be performed more effectively without routine joint distraction.[398,424]

Posterior ankle problems pose a diagnostic and therapeutic challenge because of their nature and deep location. By means of a two-portal hindfoot approach with the patient in the prone position, posterior ankle joint problems (e.g., loose bodies, ossicles, osteophytes, OCDs) can be treated.[427] In the case of a posterior impingement syndrome, bony impediments (e.g., os trigonum) can be detached and removed via the two-portal hindfoot approach.[427]

Anterior ankle arthroscopy

Indications

Ankle problems that can be managed by means of routine anterior ankle arthroscopy include soft tissue and bony impingement, synovitis, loose bodies, ossicles, and OCDs.[126] Certain ankle fractures (e.g., Weber type B distal fibular fracture, Tillaux fracture) also can be successfully treated by means of arthroscopy-assisted (open) reduction and internal fixation, which offers the advantage of direct visualization and treatment of concomitant intra-articular injuries.[305,310,379] Other procedures include arthroscopic ankle stabilization by means of radiofrequency and arthroscopy-assisted ankle arthrodesis. In case

of multiple disorders (e.g., a symptomatic OCD or ankle impingement with concomitant ankle instability), a combined treatment is often possible.

Contraindications

Absolute contraindications are infection and severe degenerative changes. Relative contraindications are degenerative changes with diminished range of motion, narrowing of the joint space, vascular disease, and edema.[124]

Diagnosis

The value of diagnostic ankle arthroscopy without a preoperative diagnosis is limited; only 26% to 43% of patients benefit from the procedure.[424,425] Hence, a diagnosis should be established preoperatively by physical examination and plain radiographs. If the diagnosis remains unclear, additional radiographs (e.g., heel rise view or anteromedial impingement view) can be obtained (Figure 1).[397,440] Furthermore, local infiltration can be performed. Temporary relief from pain after intra-articular infiltration suggests intra-articular pathology, such as soft-tissue impingement or an OCD. When and OCD, a loose body, or an ossicle is suspected, the lesion may be disclosed by magnetic resonance imaging (MRI) or spiral computed tomography (CT).[440] If the CT scan is negative and the preoperative diagnosis remains unclear, it is unlikely that the patient will benefit from diagnostic arthroscopy.[424,425]

Routine fixed distraction versus dorsiflexion

Previous investigators have reported the routine use of ankle joint distraction.[59] The available noninvasive distraction devices are sterile and attach to the operating table. A strap connected to this distraction device is placed around the ankle. The surgeon using one of these devices stands beside the patient to perform

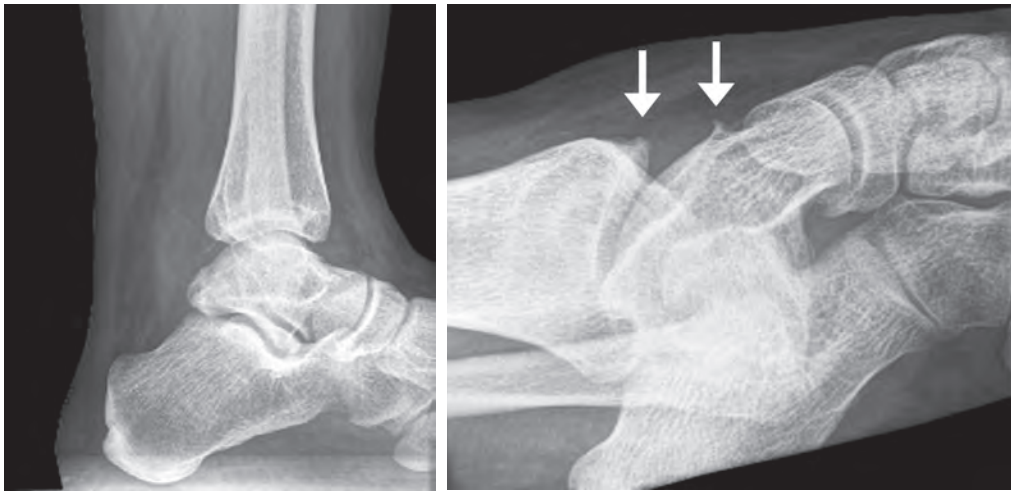

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Figure 1. Lateral (A) and anteromedial impingement (B) radiographs of the right ankle of a 32-year-old women who reported progressive pain in the right ankle for 1 year. On palpation, a recognizable tenderness on the anteromedial distal tibia was noted. In the lateral view, no pathologic structures can be visualized. In the anteromedial impingement view, talar and tibial osteophytes are clearly visible (arrows).

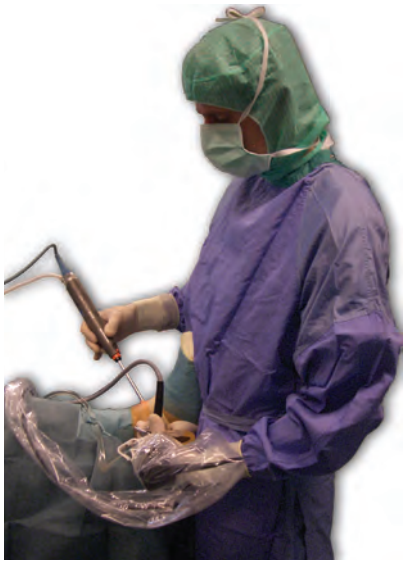

Figure 2. Positioning of the patient during anterior arthroscopy. The affected heel rests on the very end of the operating table, making it possible for the surgeon to fully dorsiflex the ankle joint by leaning against the sole of the foot.

the arthroscopic procedure. Ankle arthroscopy without distraction, however, allows the surgeon to stand at the bottom end of the operating table. In this position, the surgeon can lean against the patient's foot, thereby bringing the ankle joint into the dorsiflexed position (Figure 2).

Several factors favor the use of dorsiflexion rather than distraction. First, distraction of the joint may result in tightening of the anterior capsule, leading to a reduction of the anterior working area (Figure 3).[158] Second, loose bodies and osteophytes are usually located in the anterior compartment of the ankle joint. Dorsiflexion creates an anterior working area, which makes removal easy. Introduction of saline solution opens the anterior working area. In the case of a loose body and distraction, the loose body may fall into the posterior aspect of the joint, which makes removal more difficult. Third, in the dorsiflexed position, the talus is concealed in the joint, thereby protecting the cartilage from potential iatrogenic damage.[158]

Mechanical distraction and use of a small-diameter arthroscope may be beneficial in some situations. These include treatment of ossicles, a soft tissue impediment, a loose body caught in the joint space between the fibula and tibia (the intrinsic syndesmotic area), an OCD located in the posterior tibial plafond, and posterior ankle problems. An important alternative for the treatment of posterior ankle problems is a two-portal posterior arthroscopy.[427]

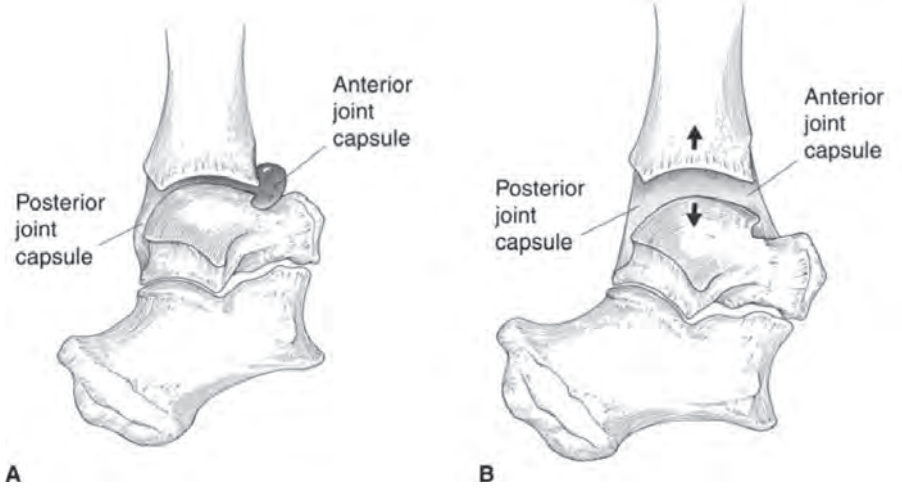

Figure 3. Schematic lateral view of the ankle joint. In dorsiflexion the anterior working is enlarged (A). Distraction of the ankle joint (arrows) results in tightening of the anterior capsule, reducing the anterior working area (B).

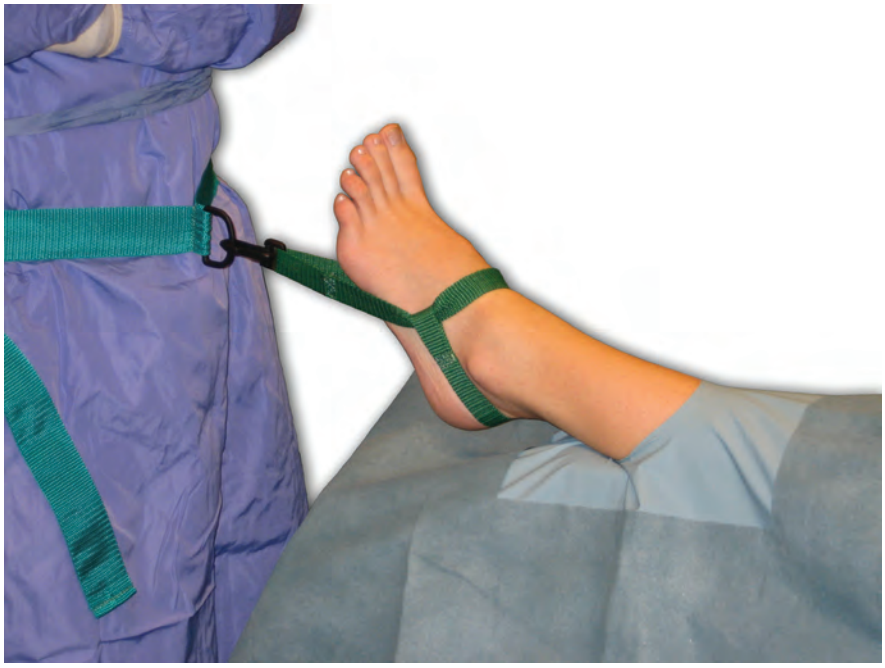

Figure 4. A resterilizable noninvasive distraction device, which permits the surgeon to move the ankle quickly from the dorsiflexed position to the distracted position and vice versa.

Should distraction be indicated, a resterilizable noninvasive distraction device enables the surgeon to change quickly from the dorsiflexed position to the distracted position and vice versa (Figure 4).[428]

Operative technique

The anterior dorsiflexion procedure is performed as outpatient surgery under general or spinal anesthesia.[424] The patient is placed in the supine position with slight elevation of the ipsilateral buttock. A tourniquet is placed around the upper thigh. The heel of the affected foot rests on the very end of the operating table, thus making it possible for the surgeon to fully dorsiflex the ankle joint by leaning against the sole of the patient's foot (see Figure 2). The two primary anterior portals used for anterior ankle arthroscopy are the anteromedial and anterolateral, located at the level of the joint line. When their use is indicated, accessory anterior portals are located just in front of the tip of the medial or lateral malleolus. Some surgeons combine the anterior portals with a posterolateral portal.[125]

The anteromedial portal is made first. After a skin incision has been made just medial to the tibialis anterior tendon, the subcutaneous layer is bluntly divided with a hemostat. The 4-mm, 30°-angle arthroscope, which we use routinely, is introduced in the fully dorsiflexed position. Saline solution is then introduced into the joint. Under arthroscopic control, the anterolateral portal is made by introducing a spinal needle lateral to the peroneus tertius tendon while respecting the superficial peroneal nerve (Figure 5).

Depending on the procedure performed, the instruments can be exchanged between portals. After removal of the instruments, the arthroscopic incisions are closed with Ethilon sutures (Ethicon, Piscataway, NJ) to prevent sinus formation.

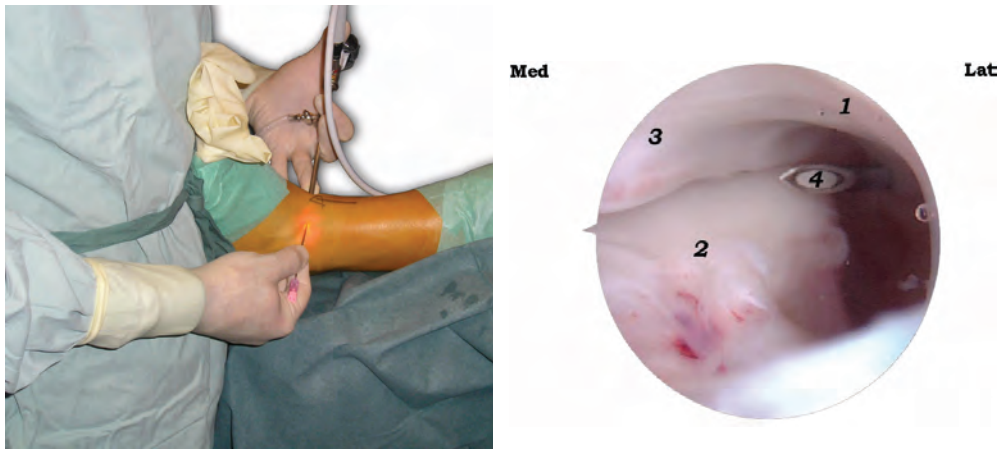

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Figure 5. Anterior arthroscopy of a left ankle; external view (A) and arthroscopic view (B). Under arthroscopic control, the anterolateral portal is made by introducing a spinal needle lateral to the peroneus tertius tendon.
AJ = anterior joint capsule, Lat = lateral, Med = medial, SN = spinal needle (guiding needle for lateral portal), Tal = talus, and Tib = tibia.

Complications

Several complications have been described, including injury to neurovascular structures, instrument breakage, articular surface damage, neuroma formation, infection, and reflex sympathetic dystrophy.[33,125,164,403] The superficial peroneal nerve is at highest risk, and injury to this nerve is associated with the anterolateral portal.[125]

Reports of complications in ankle arthroscopy vary widely. With the use of either invasive or manual constant distraction, complication rates of 9% to 17% have been reported.[33,125,164,403] In the largest series published to date, nearly 50% of complications were neurologic.[125] The use of constant distraction might be indicative of higher complication rates. In a recent survey performed in our department in which 1,300 consecutive patients with ankle arthroscopy without routine joint distraction were included, the overall percentage of complications was 3.4%. This figure includes 1.4% for hindfoot endoscopy.[430]

Osteochondral defects

An OCD is a lesion involving articular cartilage and subchondral bone. The incidence of OCDs of the talar dome in patients with acute lateral ankle ligament ruptures is 4% to 7%.[56,422] Talar OCD are usually posteromedial (58%) or anterolateral (42%).[439] Medial lesions are typically deep and cup-shaped; lateral lesions are shallow and wafer-shaped.[69] Inappropriate treatment of OCDs may eventually result in osteoarthritis of the ankle.[69]

Etiology

Previous trauma to the ankle joint is reported in 93% of lateral lesions and 61% of medial lesions.[439] In lateral lesions, the trauma mechanism is usually a combination of inversion and dorsiflexion; in medial lesions, the combination is inversion, plantar flexion and rotation.[49] In nontraumatic osteochondral defects, possible causes are genetic, metabolic, vascular, endocrine, and degenerative factors, as well as morphologic abnormalities.[49,457]

Clinical presentation

Patients with a chronic lesion typically experience persistent or intermittent deep ankle pain during or after activity, sometimes accompanied by swelling and limited range of motion. Often, on examination, few abnormalities are found. Affected ankles may have a normal range of motion with the absence of swelling and no recognizable tenderness on palpation.

Diagnosis

Routine radiographs consist of weight-bearing anteroposterior and lateral views of both ankles. The radiographs may show an area of detached bone surrounded by radiolucency. Initially, the damage may be too small to be visualized on a routine radiograph.

A heel rise mortise view may reveal a posterior defect.[440] For further diagnostic evaluation, CT and MRI have demonstrated similar accuracy.[440] A multislice helical CT scan is preferred because it is more helpful for preoperative planning (Figure 6).

Classification and staging

Several classifications based on radiography, CT, MRI, and arthroscopy have been proposed.[19,49,182,381] The first and most frequently used classification was that of Berndt and Harty:[49] stage I, a small compression fracture; stage II, incomplete avulsion of a fragment; stage III, complete avulsion of a fragment without displacement; and stage IV, displaced fragment. Scranton and McDermott later added stage V, representing cystic lesions.[349] None of the current grading systems, however, is sufficient to direct the choice of treatment.

Treatment

Various surgical techniques for the treatment of symptomatic osteochondral lesions have been published. These are generally based on one of the following three principles:[457] (1) debridement and bone marrow stimulation (microfracturing, drilling, abrasion arthroplasty); (2) securing a lesion to the talar dome (fragment fixation, retrograde drilling, bone grafting); and (3)

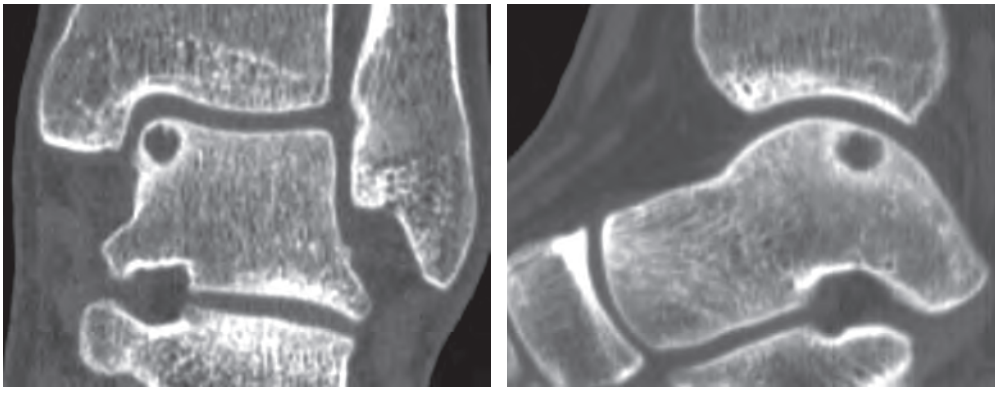

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Figure 6. Coronal (A) and sagittal (B) computed tomography reconstructions of a posteromedial osteochondral defect of the left talus in a 15-year-old girl. The patient presented with persistent deep pain on the anterior side of the left ankle and locking and giving way. One year before her visit, she had had a supination trauma, which had been treated nonsurgically.

development or replacement of hyaline cartilage (autologous chondrocyte implantation [ACI], osteochondral autograft transplantation system [OATS; i.e., mosaicplasty], allografts). The choice of treatment depends on the patient's age, symptoms, duration of complaints, and location and size of the defect, as well as whether it concerns a primary or secondary OCD.[149,457]

Asymptomatic or low-symptomatic lesions are treated nonsurgically by rest, ice, temporarily reduced weight bearing, and, in case of giving way, an orthosis.[346,457] Symptomatic lesions are treated primarily by debridement and bone marrow stimulation.[439] With this technique, all unstable cartilage is removed, including the underlying necrotic bone. Any cysts underlying the defect are opened and curetted. The sclerotic-calcified zone that is most commonly present is perforated by means of microfracturing into the vascularized subchondral bone. The underlying intraosseous blood vessels are disrupted and growth factors are released, leading to the formation of a fibrin clot into the created defect. The formation of local new blood vessels is stimulated, marrow cells are introduced into the OCD, and fibrocartilaginous tissue is formed.[301] In case of a (cystic) defect ≥15 mm in size, a cancellous bonegraft may be placed in the defect.[149]

Retrograde drilling, combined with cancellous bonegrafting when necessary, may be performed for primary OCDs when there is intact cartilage with a large subchondral cyst.[381] When primary treatment fails, OATS or ACI are options.[39,177] Although both techniques are promising, results are not yet widely published, and the number of patients included in studies is small.

OATS consists of harvesting one or more osteochondral plugs in a lesser—weight-bearing area of the knee, and transplanting them into the talar defect.[177] Although most reports show excellent results, the technique is associated with donor site morbidity, and a medial malleolar osteotomy is often required.[31,147,327] ACI is the implantation of in vitro cultured autologous chondrocytes, using a periosteal tissue cover after expansion of isolated chondrocytes. Despite excellent results reported by some investigators,[39,448] disadvantages include two-stage surgery, high costs, and reported donor site morbidity.[147,448]

Fragment fixation with one or two leg screws is preferred in acute or semiacute situations in which the fragment is ≥15 mm. In adolescents, fixation of an OCD always should be considered following failure of a 6-month period of conservative treatment.

The size and location of the lesion determine whether to use a standard 4.0-mm arthroscope and treat the OCD in the anterior working area by full plantar flexion of the ankle, or to use a 2.7-mm arthroscope in combination with mechanical distraction.[346,424] In patients with unlimited plantar flexion, all defects located in the anterior half of the talus or in the anterior part of the posterior half can be reached and treated by anterior arthroscopy.[346,424] Other options are to approach the defect from posterior by means of a two-portal hindfoot approach or to proceed by means of a medial malleolar osteotomy.[12,427]

Surgical technique and rehabilitation

A 4.0-mm scope and a 4.5- or 5.5-mm shaver are routinely used. In case of synovitis, a local synovectomy is performed with the ankle in the dorsiflexed position. The lesion is identified in the forced plantarflexed position by palpating the cartilage with a probe or hook (Figure 7). During this part of the procedure a soft-tissue distractor can be applied (see Figure 4). If possible, the full-radius resector is introduced into the defect. In doubtful cases, identifying the defect by introducing a spinal needle, probe, or curette can be useful before introduction of the resector.

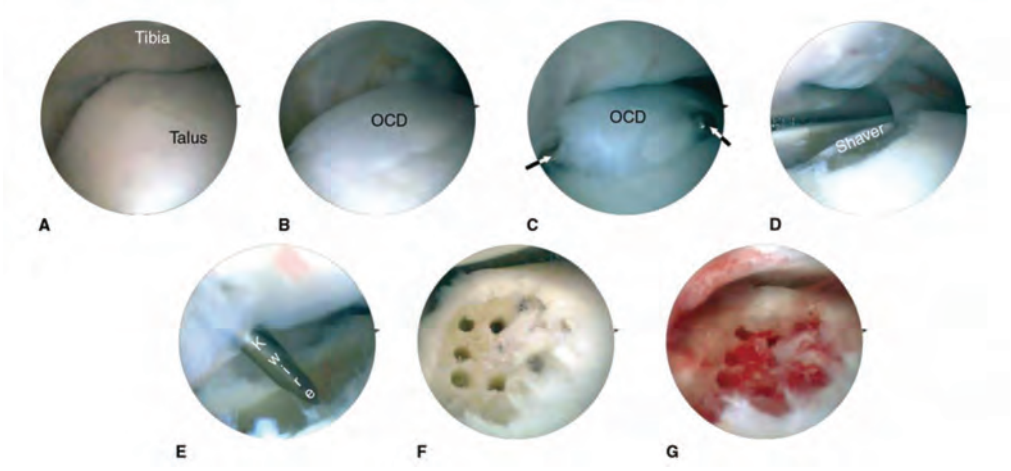


Figure 7. Arthroscopic images of debridement and drilling of a lateral osteochondral defect (OCD) of the right talus. The arthroscope is in the anteromedial portal. With the ankle in the neutral position, the OCD is out of the arthroscopic view (A). By bringing the ankle into the forced plantarflexed position, the OCD can be seen (B). The size of the lesion is identified by palpating the cartilage with a probe (arrows), which is inserted through the anterolateral portal (C). Next, a shaver is introduced for debridement of the defect (D). With the use of a Kirschner wire, small holes are drilled in the subchondral bone (E). Arthroscopic view, after switching portals, of the microfractured lesion (F). During loosening of the tourniquet, sufficient hemorrhage in the defect is checked (G).

The key to success is to identify the anterior part of the defect and remove the unstable cartilage and subchondral necrotic bone. The instruments are subsequently brought into the defect to treat the posterior part. Every step in the debridement procedure is checked by regularly switching portals. After full debridement, the sclerotic zone is penetrated by means of a microfracture probe or a Kirschner wire (see Figure 7). Postoperatively a compression dressing is applied.

Active plantar flexion and dorsiflexion are encouraged. Partial weight bearing (i.e., eggshell pressure) is allowed as tolerated. We allow progress to full weight bearing within 2 to 4 weeks in patients with central or posterior lesions of up to 1 cm. Larger lesions and anterior lesions require partial weight bearing up to 6 weeks. Running on even ground is permitted after 12 weeks.[457] Full return to normal and sporting activities is usually possible 4 to 6 months after surgery.

Results

In the treatment of osteochondral lesions, nonsurgical therapy yields a 45% success rate.[439] However, a trial period of nonsurgical treatment does not adversely affect the outcome of surgery.[12]

In a systematic review of the literature, debridement and bone marrow stimulation was superior to other methods, with a mean of 86% good or excellent results in 21 studies (total, 272 patients).[439] However, OATS and ACI were not included because of the few number of studies using these methods, and sizes of the treated lesions were not described.

A recent randomized controlled that compared chondroplasty, microfracture, and OATS showed similar results among these methods at 2-year follow-up.[156] However, the chondroplasty and microfracture techniques are recommended because of less postoperative pain. Furthermore, costs are lower compared with those of other techniques.[147]

Anterior ankle impingement

Chronic anterior ankle pain is commonly caused by formation of tibial or talar osteophytes at the anterior part of the ankle joint. Morris and later McMurray named this condition athlete's ankle or footballer's ankle;[279,292] these terms were later replaced by the anterior ankle impingement syndrome. The condition predominantly affects soccer players, but it also occurs in runners, ballet dancers, high jumpers, and volleyball players.[398]

Etiology

Various theories exist regarding the causes of anterior impingement: traction, trauma, recurrent microtrauma, and chronic ankle instability.[50,93,279,395] The hypothesis of traction is not plausible because the anterior joint capsule is attached more proximally to the site where the tibial spurs originate.[394,396,426]

In trauma secondary to or associated with supination stress, damage to the non—weight-bearing cartilage rim occurs.[422] A repair reaction is initiated, with cartilage proliferation, scar tissue formation, and calcification. Ankle sprains resulting from chronic instability as well as forced dorsiflexion enhance this process.[50,232]

The pain in anterior ankle impingement likely is caused by the inflamed soft tissue along the anterior tibiotalar joint line, which is compressed by the talar and tibial osteophytes during forced dorsiflexion.[396,431]

Clinical presentation

Anterior ankle impingement is characterized by anterior pain at the level of the ankle joint, swelling after activity, and, occasionally, limited dorsiflexion.[93] Athletes with recurrent ankle sprains are prone to this condition, and sporting activities are often reduced because of the pain.

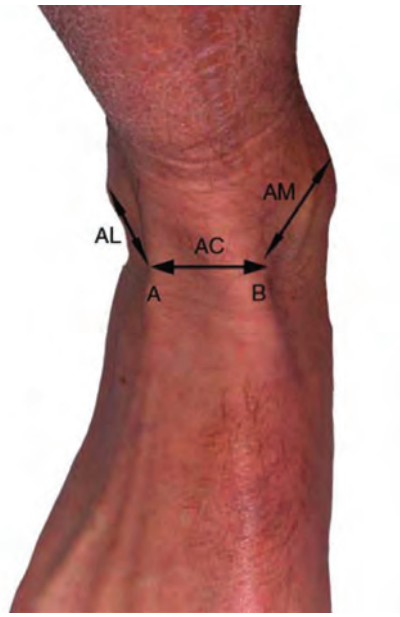


Figure 8. Localization of anterior impingement. When a patient recognizes the local tenderness on palpation lateral to the peroneus tertius tendon (A) or medial to the tibialis anterior tendon (B), the diagnosis of anterolateral or anteromedial impingement is made, respectively.

AC = anterocentral region, AL = anterolateral region, and AM = anteromedial region.

On palpation, recognizable tenderness is noted on the anterior bone at the joint level. Tenderness on palpation medial to the tibialis anterior tendon indicates anteromedial impingement; tenderness lateral to the peroneus tertius tendon indicates anterolateral impingement (Figure 8).[431] Forced hyperdorsiflexion may provoke the pain, but this test is often false-negative.

Diagnosis

Standard anteroposterior and lateral radiographs may not detect the presence of osteophytes. When anteromedial osteophytes are suspected, an oblique radiograph should be added because some osteophytes may be undetected by standard radiographs.[397] Anteromedial tibial or

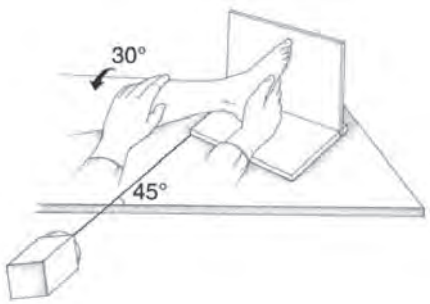


Figure 9. In the oblique anteromedial impingement view, the beam is tilted 45° in a craniocaudal direction, with the leg in 30° external rotation and the foot in plantar flexion in relation to the standard lateral radiograph position.

talar osteophytes may be overprojected by the anterolateral border of the distal tibia or by the lateral part of the talar neck and body, respectively. In the oblique anteromedial impingement view, the beam is tilted in a 45° craniocaudal direction, with the leg in 30° external rotation and the foot in plantar flexion in relation to the standard lateral radiograph position (Figure 9). The anteromedial impingement radiograph has a high sensitivity for detecting anteromedial osteophytes: 93% for tibial and 67% for talar osteophytes (see Figure 1).[397]

Treatment and rehabilitation

Although nonsurgical treatment such as intra-articular injections and heel lifts is recommended in the early stage of anterior ankle impingement, outcome is frequently disappointing. The arthroscopic approach is performed as described above. With the ankle in the dorsiflexed position, the contour of the anterior tibia is identified by shaving away the tissue just superior to the osteophyte. A 4-mm chisel and/or motorized shaver system is subsequently used to remove them.

A compression bandage is applied, and partial weight bearing for 3 to 5 days is permitted as tolerated. Active dorsiflexion is encouraged.

Results

Open resection and arthroscopic resection of osteophytes were compared by Scranton and McDermott.[348] The average length of hospitalization and time to recovery were shorter in the arthroscopic group.

In prospective studies, success rates varied from 73% to 96%.[15,38,426] A significant difference in outcome was seen between patients with normal joint spaces and (90% success) and those with joint space narrowing (50% success).[426] This finding was later confirmed in two long-term follow-up studies.[86,394] Because the alternative in these osteoarthritic patients is arthrodesis, a 50% success rate is acceptable. Both series also reported a high rate of recurrence of osteophytes.[86,394] However, no statistical correlation was seen between recurrence of osteophytes and return of symptoms.

Hindfoot endoscopy

History

The deep location of hindfoot structures makes direct access difficult. Historically, the hindfoot was approached by a three portal technique (i.e., anteromedial, anterolateral, posterolateral), with the patient in the supine position.[125] The traditional posteromedial portal is associated with potential damage to the tibial nerve, the posterior tibial artery, and local tendons.[124]

A two-portal endoscopic approach with the patient in the prone position was introduced in 2000.[427] This technique has been shown to provide excellent access to the posterior ankle compartment, the subtalar joint, and extra-articular structures.[427]

Indications

The main indications for endoscopy in the posterior compartment of the talocrural joint are posteriorly located OCDs of the ankle joint, loose bodies, ossicles, posttraumatic calcifications or avulsion fragments, posterior tibial rim osteophytes, chondromatosis, and chronic synovitis.[430] In the posterior compartment of the subtalar joint, the main indications are osteophytes, loose bodies, an intraosseous talar ganglion, and subtalar arthrodesis. Other extra-articular structures that can potentially be treated are the posterior tibial tendon, the flexor hallucis longus tendon, the peroneal tendons, the Achilles tendon, the deep portion of the deltoid ligament, and a symptomatic os trigonum or hypertrophic talar process.[430]

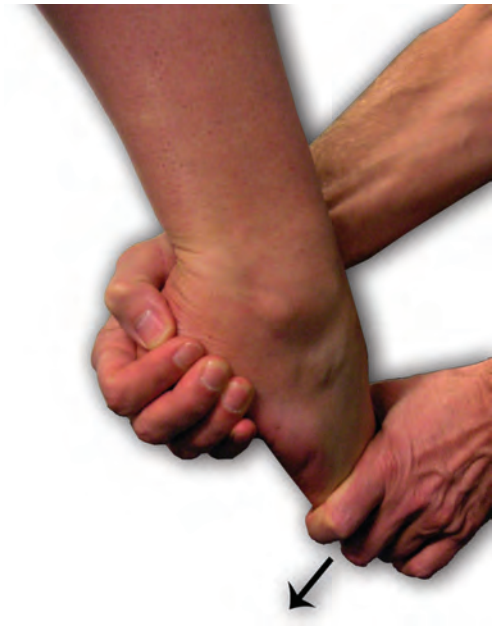


Figure 10. The forced hyperplantarflexion test. The patient is sitting with the knee flexed in 90°. The test is performed by repetitive, quick, passive hyperplantarflexion movements (arrow). This may be repeated in slight external or internal rotation of the foot. The investigator may apply this rotational movement on the point of maximal plantar flexion, thereby "grinding" the posterior talar process or os trigonum between tibia and calcaneus.

Posterior ankle impingement

Posterior ankle impingement syndrome is a clinical diagnosis in which the patient experiences pain in the hindfoot when the ankle is forced into a plantarflexed position (Figure 10). It is caused by overuse or trauma and mainly occurs in ballet dancers, downhill runners, and soccer players.[431]

After an injection of lidocaine, the forced hyperplantarflexion test should be negative. On plain radiographs and CT, an os trigonum or hypertrophic posterior talar process may be detected. Treatment consists of resection of a symptomatic os trigonum, reduction of a prominent posterior talar process, or removal of a soft-tissue impediment.

Surgical technique and rehabilitation

The procedure is performed as outpatient surgery under general or spinal anesthesia. The patient is placed in a prone position. A tourniquet is applied around the upper leg, and a small support is placed under the lower leg, making it possible to move the ankle freely (Figure 11). A soft-tissue distraction device can be used when indicated.[428] For irrigation, normal saline with gravity flow is suitable. A 4.0-mm, 30° arthroscope is routinely used for posterior ankle arthroscopy. In addition to the standard excisional and motorized instruments for treatment of osteophytes and ossicles, a 4-mm chisel and small periosteal elevator can be useful.

With the ankle in the neutral position, a line is drawn from the tip of the lateral malleolus to the Achilles tendon, parallel to the foot sole. The posterolateral portal is situated just above this line, in front of the Achilles tendon (Figure 12A). After a vertical stab incision is made, the subcutaneous layer is split by a mosquito clamp. The mosquito clamp is directed anteriorly, pointing in the direction of the interdigital web space between the first and second toe (Figure 13).

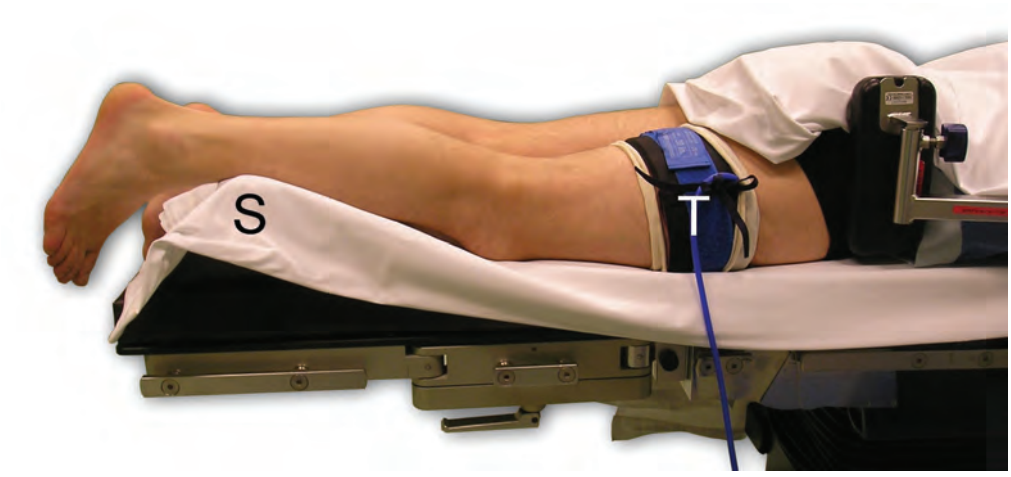


Figure 11. During hindfoot endoscopy the patient is placed in the prone position. A tourniquet (T) is applied around the upper leg, and a small support (S) is placed under the lower leg, which makes it possible to move the ankle freely.

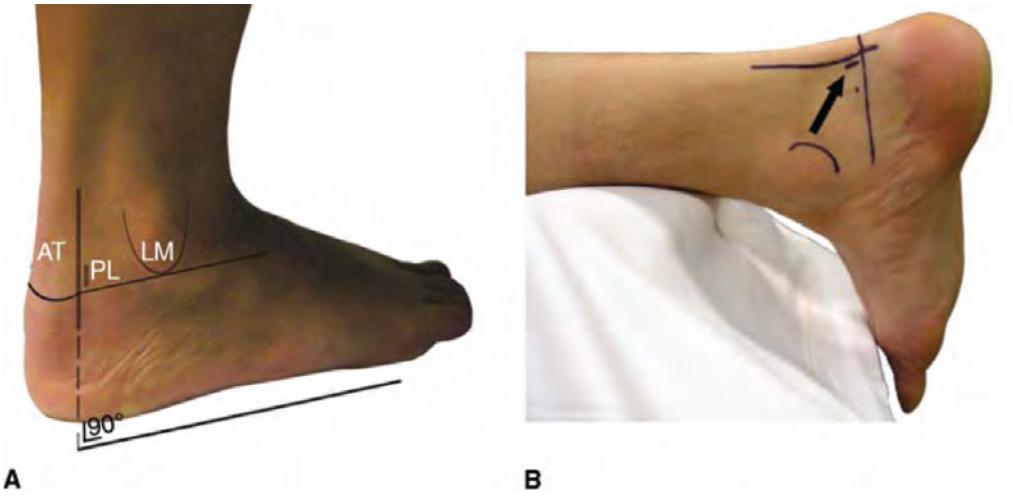


Figure 12. Portal placement in a right ankle during hindfoot endoscopy. The posterolateral portal (PL) is made just above the line from the tip of the lateral malleolus (LM) to the Achilles tendon (AT), parallel to the foot sole, just in front of the Achilles tendon (A). The posteromedial portal is made at the same level as the posterolateral portal, just above the line from the tip of the lateral malleolus, in front of the medial aspect of the Achilles tendon (B).

1 = posterolateral portal, 2 = lateral malleolus, and 3 = Achilles tendon.

When the tip of the clamp touches the bone, it is exchanged for a 4.0-mm arthroscope. The direction of view is 30° to the lateral side.

The posteromedial portal is now made at the same level (Figure 12B). After making a vertical stab incision in front of the medial aspect of the Achilles tendon, a mosquito clamp is introduced and directed toward the arthroscope shaft in a 90° angle. When it touches the shaft of the arthroscope, it is moved anteriorly in the direction of the ankle joint, all the way down, touching the arthroscope shaft until it reaches the bone (Figure 14). The arthroscope is now pulled slightly backward until the tip of the mosquito

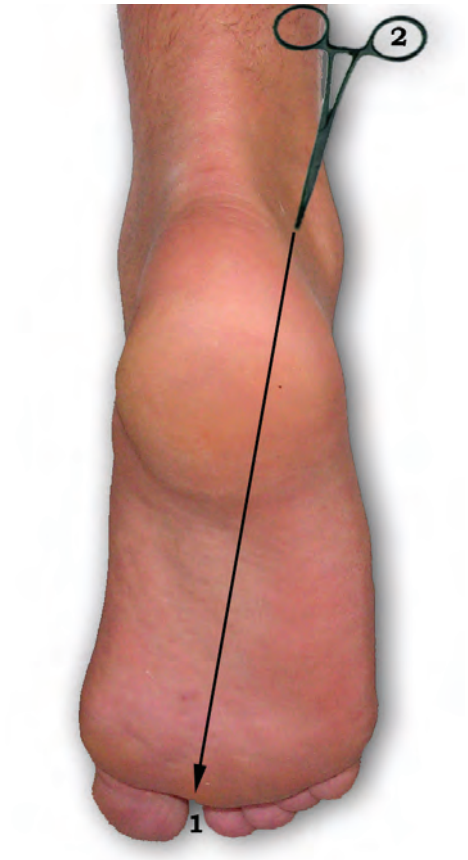


Figure 13. The posterolateral instrument (2) is directed anteriorly, pointing in the direction of the interdigital web space between the first and second toe (1).

clamp comes in to view. The clamp is used to spread the extra-articular soft tissue in front of the tip of the lens. In situations where scar tissue or adhesions are present, the mosquito clamp is exchanged for a 4.5-mm full-radius shaver.

After removal of the very thin joint capsule of the subtalar joint by a few turns of the shaver, the posterior compartment of the subtalar joint can be visualized. At the level of the ankle joint, the posterior tibiofibular and talofibular ligaments are recognized. The posterior talar process can be freed of scar tissue, and the flexor hallucis longus tendon is identified. The flexor hallucis longus tendon is an important landmark to prevent damage to the medial neurovascular bundle (Figure 15). One should always stay lateral to this tendon and move medially only when release of the neurovascular bundle is indicated (e.g., tarsal tunnel syndrome). After removal of the thin joint capsule of the ankle joint, the ankle joint can be entered and inspected.

Removal of a symptomatic os trigonum or treatment of a nonunion of a posterior talar process fracture involves partial detachment of the posterior talofibular ligament, release of the flexor retinaculum, and release of the posterior talocalcaneal ligament (Figure 16). The os trigonum can be lifted from the subtalar joint by means of a small-sized bone elevator (Figure 17) and removed with a grasper. At the end of the procedure, hemorrhage is controlled by electrocautery, and the skin is closed with Ethilon sutures. A sterile compression dressing is applied.

Postoperative treatment is functional and consists of weight bearing on crutches as tolerated for 3 days, after which the dressing is removed. The patient is advised to start range-of-motion exercises as soon as possible after surgery. If necessary, physiotherapy is begun.

Results

We performed 146 endoscopic hindfoot procedures on 136 consecutive patients.[430] The main indications were bony impingement, OCDs, and flexor hallucis longus tendinitis. Treatment was successful in most patients; two minor complications (1.4%) were seen (i.e., an area of diminished sensation over the heel pad of the hindfoot in both cases).[430] Similar results have been published by other surgeons.[453] Furthermore, the technique described is considered to be a safe method, according to a recent anatomic study.[250] It is recommended that the procedure be performed by an experienced arthroscopist who has practiced this type of surgery in a cadaveric setting at arthroscopy courses.

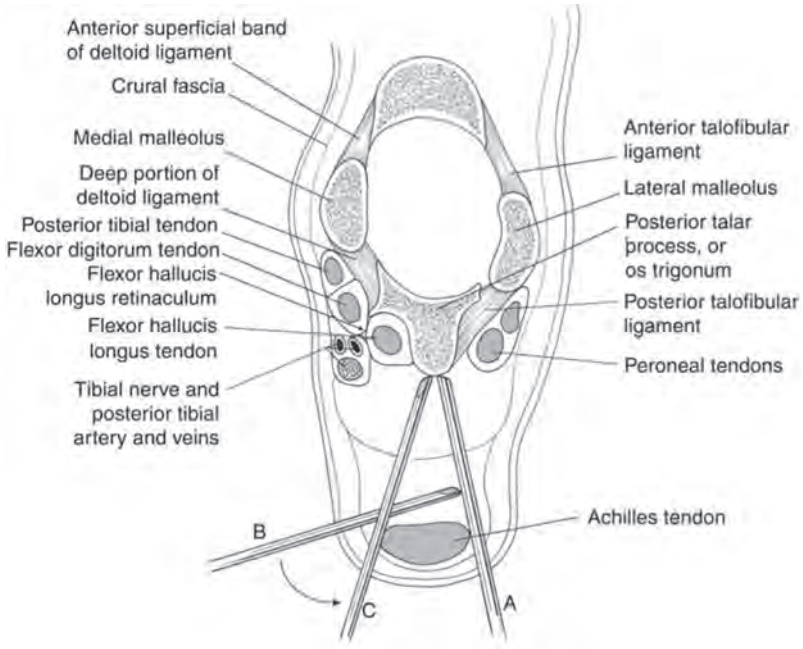


Figure 14. Schematic transverse section of the right ankle joint at the level of the arthroscope. The posterolateral portal is made first (A). The arthroscope is directed toward the first web space. The posteromedial portal is made at the same level (B). The mosquito clamp is directed toward the arthroscope shaft at a 90° angle. When the mosquito clamp touches the shaft of the arthroscope, the clamp is moved anteriorly in the direction of the ankle joint, all the way down, touching the arthroscope shaft until it reaches the bone (curved arrow) (C). All following instruments (e.g., shaver) are introduced in the same manner.

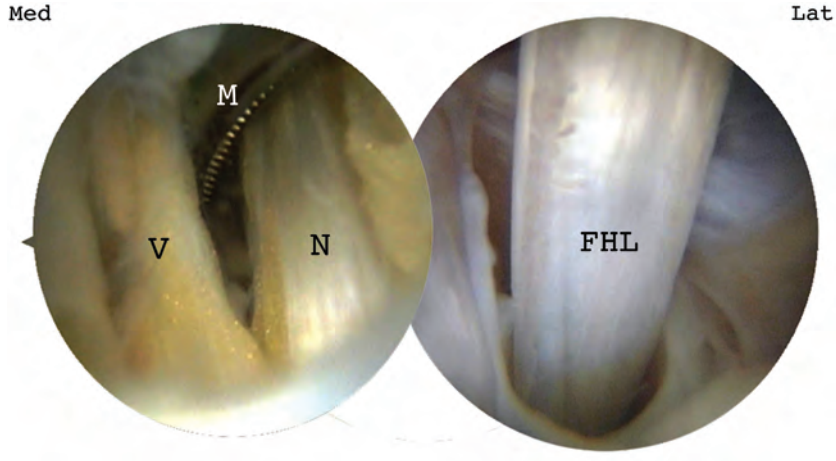


Figure 15. Hindfoot endoscopy of the right ankle. A combination of two separate procedures is shown. The flexor hallucis longus (FHL) is the important landmark in posterior ankle arthroscopy. Instruments should always stay lateral to this tendon. Viewing medial to the FHL (left) reveals the neurovascular bundle (tibial nerve [N], and the posterior tibial artery and veins [V]). This medial view is only indicated when a tarsal tunnel release is performed.

Lat = lateral, M = mosquito clamp in lateral portal, and Med = medial.

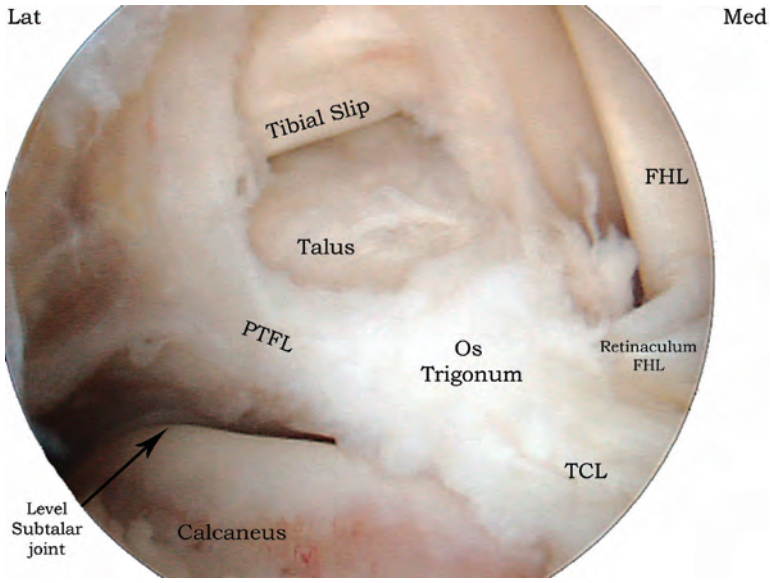


Figure 16. Endoscopic picture of a left ankle. Removal of a symptomatic os trigonum or treatment of a nonunion of a posterior talar process fracture involves partial detachment of the posterior talofibular ligament (PTFL), release of the flexor hallucis longus (FHL) retinaculum, and release of the posterior talocalcaneal ligament (TCL).

Lat = lateral and Med = medial.

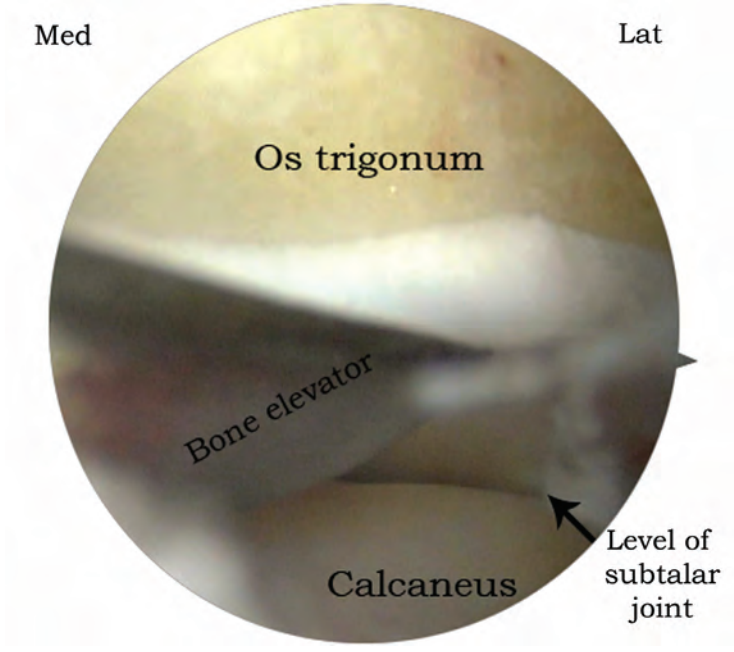


Figure 17. Endoscopic view of a right ankle. The os trigonum can be lifted from the subtalar joint with a small bone elevator.

Lat = lateral and Med = medial.

Summary

Over the last three decades, the field of arthroscopic foot and ankle surgery has progressed significantly. Arthroscopy of the ankle joint has become the procedure of choice for the treatment of chronic and posttraumatic pathologies. The diagnosis should be established before surgery. If necessary, CT and additional radiographs (e.g., heel rise view, anteromedial impingement view), can be obtained to confirm a clinical diagnosis and for preoperative planning. When the dorsiflexed position is used with anterior arthroscopy, ankle distraction is necessary only in a minority of cases.

Most OCDs can be treated by anterior arthroscopic debridement and microfracturing with the ankle in planter flexion. The anterior impingement syndrome is treated by arthroscopic excision of osteophytes. Posterior ankle problems (e.g., posterior impingement syndrome) can be effectively treated by means of a two-portal hindfoot approach with the patient in the prone position. This approach offers excellent access to the posterior ankle compartment, the subtalar joint, and extra-articular structures.

Acknowledgment

Peter A.J. de Leeuw, PhD fellow, is gratefully acknowledged for the kind preparation of figures 1, 4 through 13, and 15 through 17.

Part II
Primary arthroscopic debridement and bone marrow stimulation

Chapter 4

Computed tomography of the ankle in full plantar flexion: a reliable method for preoperative planning of arthroscopic access to osteochondral defects of the talus

Christiaan J.A. van Bergen
Gabriëlle J.M. Tuijthof
Leendert Blankevoort
Mario Maas
Gino M.M.J. Kerkhoffs
C. Niek van Dijk

Arthroscopy
2012;28(7):985-992.

Abstract

Purpose

The purpose of this study was to determine whether preoperative computed tomography (CT) of the ankle joint in full plantar flexion is a reliable and accurate tool to determine the anterior arthroscopic accessibility of talar osteochondral defects (OCDs).

Methods

Twenty consecutive patients were prospectively studied. All patients had an OCD of the talar dome and had a preoperative CT scan of the affected ankle in maximum plantar flexion. Accessibility of the OCD was defined by the distance between the anterior border of the OCD and the anterior distal tibial rim. This distance was measured on sagittal CT reconstructions by two investigators. The reference standard was the distance between the same landmarks measured during anterior ankle arthroscopy by an orthopedic surgeon blinded to the CT scans. Intraobserver and interobserver reliability of CT, as well as the correlation and agreement between CT and arthroscopy, were calculated.

Results

The measured distance between the anterior border of the OCD and the anterior distal tibial rim ranged from -3.1 to 9.1 mm on CT and from -3.0 to 8.5 mm on arthroscopy. The intraobserver and interobserver reliability of the measurements made on CT scans (intraclass correlation coefficients >0.99, p <0.001), as well as the correlation between CT and arthroscopy, were excellent (r = 0.98; p <0.001).

Conclusion

Measurements on CT scans of the ankle in full plantar flexion are a reliable and accurate preoperative method to determine the in situ arthroscopic location of talar OCDs.

Introduction

Osteochondral defects (OCD) of the talus involve the articular cartilage and subchondral bone and are usually located on the central or posterior third of the medial or lateral talar dome.[322] The primary surgical treatment for these lesions is arthroscopic debridement and microfracture.[458] Arthroscopic access to the talar dome is restricted by the tibial plafond. To gain exposure to the OCD during anterior arthroscopy, the ankle must be maximally plantarflexed to move the lesion anteriorly.[424,432] However, some defects located in the posterior part of the talus may not be accessible by anterior arthroscopy.[296,408] Especially if the OCD is located posteriorly and if there is restricted range of motion of the ankle, determining accessibility of the lesion preoperatively may be difficult. Accurate preoperative planning will assist the surgeon in choosing whether anterior arthroscopy or another surgical approach would be appropriate.

Radiographs can be used for the initial diagnosis, but multislice helical computed tomography (CT) and magnetic resonance imaging (MRI) have higher accuracy in detecting OCDs.[440] CT scanning is preferred for preoperative planning because it visualizes the exact location, size and extent of the OCD.[160,408] CT scanning of the ankle is normally performed with the ankle joint in the plantigrade position. This position is different from the plantarflexed ankle on anterior ankle arthroscopy. A CT scan of the ankle in full plantar flexion, simulating the arthroscopic positioning, may better show the intraoperative location of the OCD and could thus be an important tool for preoperative planning.

The purpose of this study is to determine whether a preoperative CT scan of the plantarflexed ankle is able to predict the anterior arthroscopic accessibility of talar OCDs. We hypothesized that the location of the OCD in relation to the anterior distal tibial rim on a CT scan of a fully plantarflexed ankle would correlate with the location as measured during anterior ankle arthroscopy.

Methods

Study design

A prospective study was undertaken according to a study protocol approved by the local medical ethics committee. Patients aged 18 years or older presenting to our outpatient department with a suspected or diagnosed OCD of the talus starting in May 2008 were eligible for the study. After informed consent was obtained, CT scans of the affected ankle in both the plantigrade and fully plantarflexed positions were obtained (Figure 1). The surgeon (blinded to the CT scan of the plantarflexed ankle) made the decision for treatment, based on the CT scan of the plantigrade ankle and the clinical assessment of the ankle range of motion and joint laxity. The first 20 patients with an OCD who were scheduled for treatment by anterior ankle arthroscopy (June 2008 to March 2009) were included in the study. A sample size of 19 was able to detect a reliability of 0.9 and a minimally acceptable reliability of 0.7, with $\alpha = 0.05$ and $\beta = 0.20$.[443] During the study period, we excluded 10 patients who were scheduled for treatment by methods other than anterior ankle arthroscopy: two were treated by posterior arthroscopy[427] – the first for a far posterolateral OCD and the second for a posteromedial OCD combined with a loose body in the posterior ankle compartment – and eight were treated with a focal resurfacing implant[412] through a medial malleolar osteotomy for a large OCD of the medial talar dome that failed previous surgical treatment.

Accessibility of the OCD was defined by the distance between the anterior border of the OCD and the anterior distal tibial rim. This distance was measured on sagittal CT reconstructions and compared to anterior ankle arthroscopy as the reference standard. The anterior edge of the lesion rather than the middle or posterior portion was chosen as the landmark for accessibility since it is the anterior part of the lesion that has to be identified initially during arthroscopy. The defect is then treated from anteriorly to posteriorly, thus gaining further exposure during treatment. Removal of the anterior part of the defect cartilage will automatically create more space for access to the more posterior defect area. By forcing the ankle into full plantar flexion, the ankle opens up anteriorly, thus providing access to the complete defect. Adding a noninvasive ankle distractor can also be helpful at this point.

Computed tomography

With the patient supine, CT scans of the affected ankles were acquired in the plantigrade (i.e., the foot sole perpendicular to the table) and

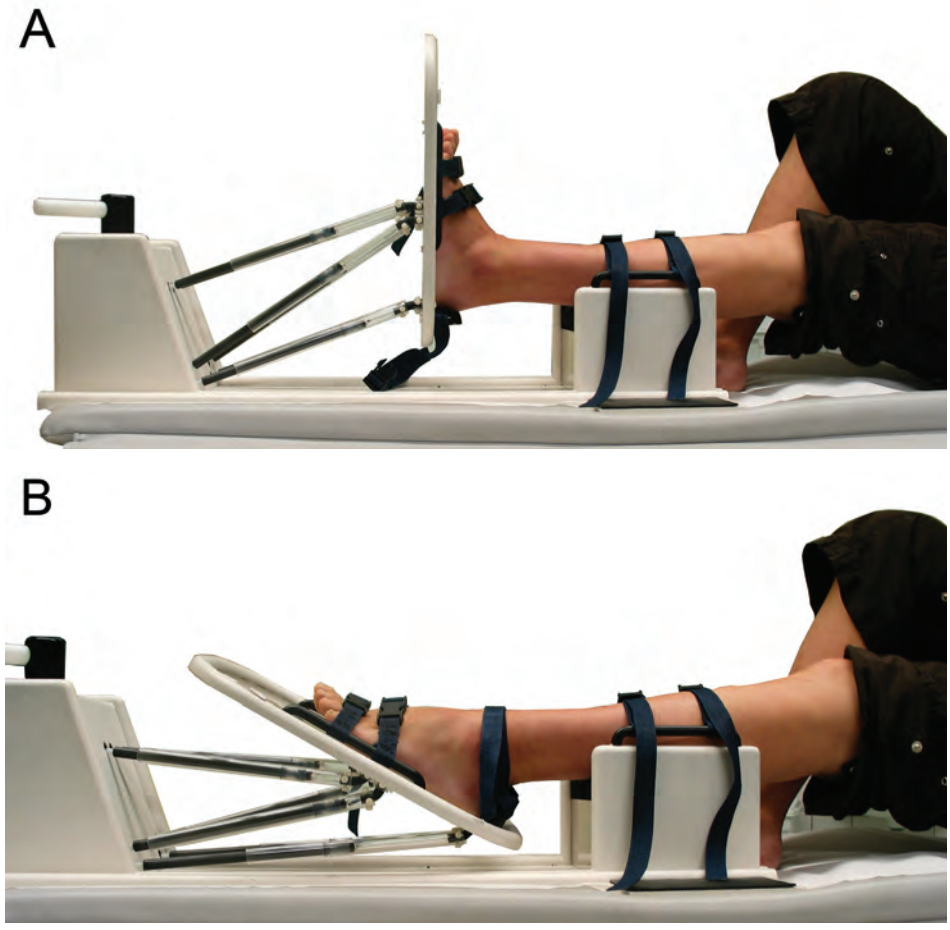


Figure 1. By use of a specially developed 3-dimensional footplate, the affected ankle was fixed and scanned (A) in the neutral (plantigrade) position and (B) in full plantar flexion.

fully plantarflexed ankle positions, using a metal-free 3-dimensional footplate developed in our department (Figure 1). The affected lower leg was placed on a platform positioned 10 cm above the table to allow slight knee flexion and ankle relaxation. The foot was attached to the footplate. The ankle was then manually positioned in maximal plantar flexion, and the footplate was secured in place. Before the scan, we measured the degree of plantar flexion of the affected ankle with a goniometer, using the dorsum of the foot and the anterior side of the lower leg as landmarks in both the neutral and the plantarflexed ankle positions and then subtracting the neutral from the plantarflexed position.

The CT scan was performed analogous to the protocol described by Beimers et al.[46] Sagittal 1.0-mm slices were reformatted in two planes, because the lateral and medial talar facets have different anatomic orientations; one set of reconstructions was made parallel to the lateral talar facet and one set parallel to the medial talar facet. These sagittal planes were identified on the original axial scans and reformatted in a standardized fashion. The reconstructed images parallel to the lateral talar facet were used for the

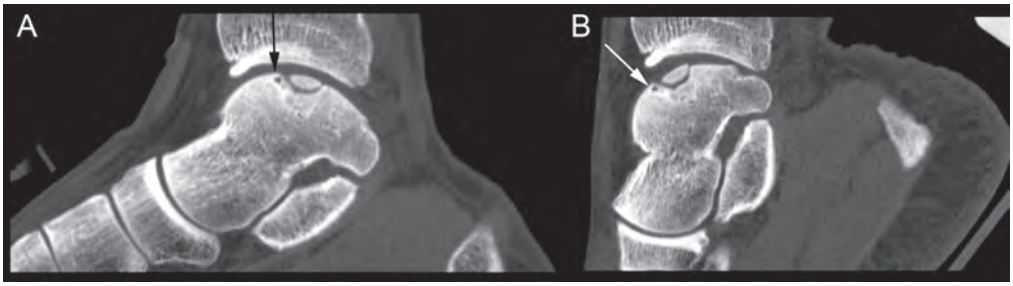


Figure 2. Sagittal reconstructed images of CT scans of an ankle (A) in neutral position and (B) in full plantar flexion. The tube current was 150 mAs for the neutral position and 26 mAs for the plantarflexed position. Although low-dose scans had a lower signal-to-noise ratio, this did not hamper delineation of the defects. The anterior border of the OCD is indicated by the arrows.

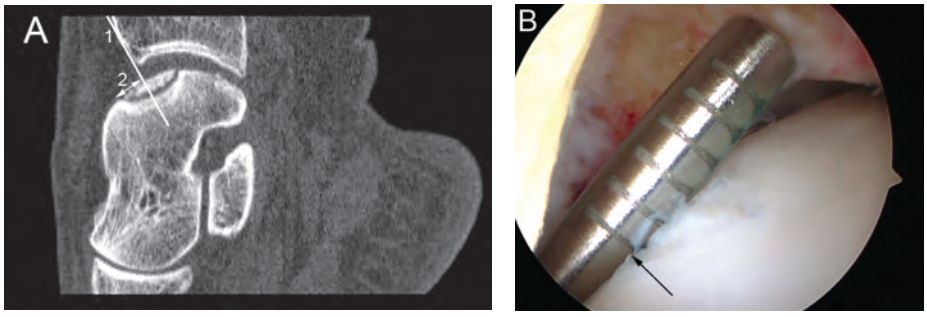


Figure 3. Analysis of a patient with a centromedial OCD. (A) On the CT scan, a tangent line (1) of the anterior distal tibial rim was drawn perpendicularly to the talar dome. The distance (2) from the anterior border of the OCD to this line was measured. (B) During arthroscopy, the distance between the anterior distal tibial rim and anterior border of the defect (arrow) was measured with a specially developed arthroscopic ruler. On this ruler, the first line is 2 mm from the tip and each following line is 1 mm more from the tip, up to 7 mm.

assessment of OCDs located on the lateral talar dome, whereas the images parallel to the medial facet were used for the defects located on the medial talar dome.

For descriptive purposes, the original axial slices of the neutrally positioned ankles were used to divide the location of the OCDs into nine regions according to the anatomic nine-grid scheme described by Raikin et al.[322] For further analysis, the anteromedial, anterocentral, and anterolateral locations were combined into the anterior third of the talar dome; the centromedial, centrocentral, and centrolateral into the central third; and the posteromedial, posterocentral, and posterolateral into the posterior third.

The anterior border of the OCD and the anterior distal tibial rim (i.e., anterior edge of the tibial plafond) were digitally marked on the sagittal reconstructions by the first author in consultation with an orthopaedic surgeon and a musculoskeletal radiologist, using the tools present on the picture archiving and communication system (Impax 5.3.1, Agfa-Gevaert NV, Mortsel, Belgium) of the radiology department. The anterior border of the OCD was defined as the most anterior point of the bony lesion (Figures 2 and 3). Next, two investigators independently measured the distance from the anterior border of the OCD to the anterior distal tibial rim (Figure 3A) as defined by the marks. To analyze intraobserver reliability of the CT measurements, one

investigator (blinded to the first sequence) measured a second time, with a different order of scans.

Arthroscopy

All patients were treated in the supine position under general or spinal anesthesia, with a tourniquet around the upper leg, by a standard arthroscopic technique as previously described.[424,432] Anteromedial and anterolateral portals were created at the level of the joint line with the ankle initially in dorsiflexion. No additional portals were needed. A 4-mm, 30° arthroscope was routinely used. A local synovectomy around the portal opposite the defect was performed when necessary. With the arthroscopic instruments in the ankle joint, the OCD was brought into view by full plantar flexion of the ankle, which was carried out manually by the assistant. The anterior border of the defect was identified with an arthroscopic hook. The surgeon, blinded to the plantarflexion CT scan, measured the anteroposterior distance between the anterior border of the OCD and the anterior distal tibial rim with the patient's ankle in full plantar flexion, using a specially developed arthroscopic ruler (Figure 3B). After the measurement, in some difficult cases, a small bony rim or osteophyte of the anterior distal tibia was removed with a bonecutter shaver, or noninvasive distraction with a strap around the ankle[428] was used to improve exposure. The OCD was treated by debridement from anteriorly to posteriorly and additional microfracturing with a curved microfracture awl. Routine postoperative care and follow-up were arranged.[432]

Statistical analysis

The intraobserver and interobserver reliability of the CT measurements were analyzed by computation of intraclass correlation coefficients (ICC) and systematic differences with 95% confidence intervals (CIs) (paired t-test). According to Fleiss, the reliability is considered good if the ICC is 0.40 to 0.75 and excellent if the ICC is more than 0.75.[134] The mean of both observers' first series of measurements was used for further analysis, as proposed by Bland and Altman.[51] The correlation of CT and arthroscopic measurements was analyzed by Pearson's correlation coefficient (r). A scatter plot and linear regression analysis were used to analyze the relationship between CT and arthroscopy. Agreement between both measurements was visualized by plotting a Bland and Altman graph.[51] This is a rather strict statistical method for assessing agreement between two methods of clinical measurement and tends to reject rather than falsely accept the new method.[51] A difference between CT and arthroscopic values of less than 2.0 mm was defined as clinically acceptable. This cut off was based on the experience that OCDs within 2 mm of arthroscopic reach can be accessed by shaving off a small rim of the anterior distal tibia. The limits of agreement were calculated (i.e., the mean difference ± 2 × standard deviation of the mean difference). $P < 0.05$ was considered statistically significant.

Results

The study included 20 consecutive patients (17 men and three women) with a mean age of 33 years (range, 18 – 55 years). In 10 patients the right ankle was affected and in 10 the left. The mean degree of plantar flexion was 42° (standard deviation, 10°). According to the anatomic grid scheme, 10 OCDs were located on the centromedial talar dome, four posteromedial, three centrolateral, one posterolateral, one anterolateral, and one centrocentral. When combined in thirds from anterior to posterior, the defect was anterior in one patient (5%), central in 14 (70%), and posterior in five (25%) (Figure 4).

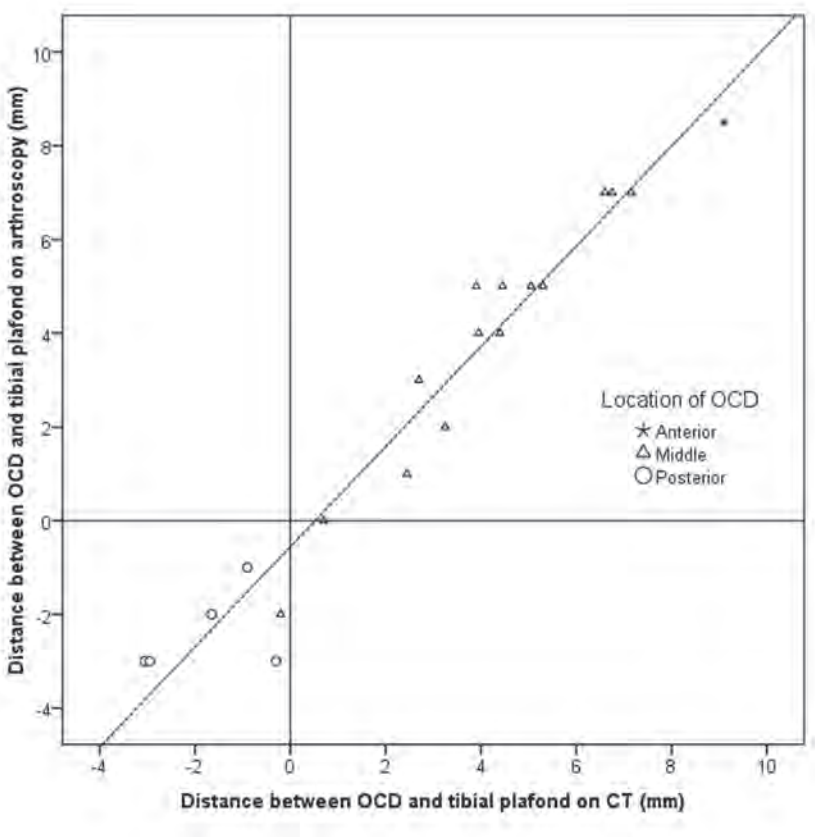


Figure 4. Scatter plot of distance between anterior border of talar osteochondral defect (OCD) and anterior distal tibial rim as measured on CT (x-axis) and anterior ankle arthroscopy (y-axis). The dashed line indicates the relation of these measurements as calculated by linear regression (y = 1.069x – 0.557). The distribution of different OCD locations (anterior one-third, middle one-third, and posterior one-third of talar dome) is shown.

On CT, the measured distances between the anterior distal tibial rim and the anterior border of the OCD were as follows. The first observer's first sequence ranged from -2.9 to 9.3 mm (mean, 3.0 mm); the second sequence ranged from -2.8 to 9.2 mm (mean, 3.0 mm). The second observer's measurements ranged from -3.3 to 8.9 mm (mean, 2.7 mm). The mean of both observers' first series of measurements ranged from -3.1 to 9.1 mm (mean, 2.8 mm) (Figure 4). When separated for the anterior, central, and posterior OCDs, the distance measure was 9.1 mm, -0.2 to 7.2 mm (mean, 4.0 mm), and -3.1 to -0.3 mm (mean, -1.8 mm), respectively. Both the intraobserver reliability and interobserver reliability were excellent (ICC, 0.998 and 0.997, respectively; p <0.001). The intraobserver systematic difference was not statistically significant (mean, 0.051 mm, 95% CI, -0.061 to 0.15 mm), but there was a significant interobserver systematic difference (mean, 0.37 mm; 95% CI, 0.24 to 0.50 mm; p <0.001).

With arthroscopy, the measured distance between the anterior distal tibial rim and the anterior border of the OCD ranged from -3.0 to 8.5 mm (mean, 2.5 mm) (Figure 4). The distance measure was 8.5 mm for the anterior lesion, -2.0 to 7.0 mm (mean, 3.8 mm) for the central lesions, and -3.0 to -1.0 mm (mean, -2.4 mm) for the posterior lesions, respectively.

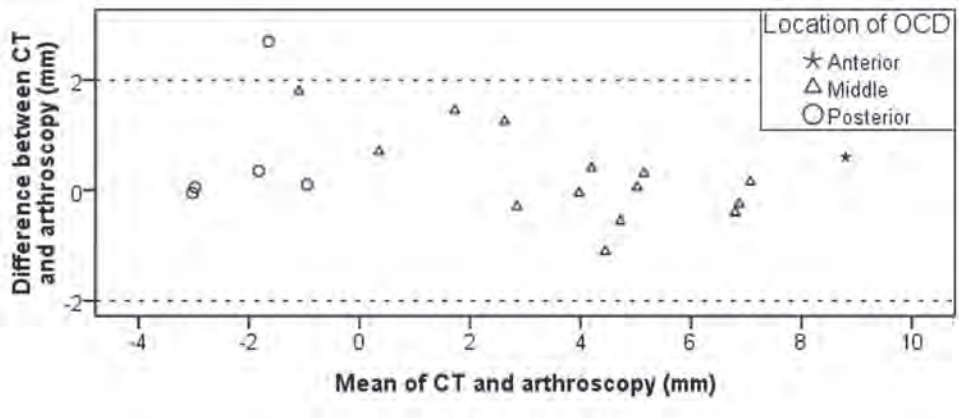


Figure 5. Bland and Altman plot[51] showing difference against mean of distances measured on CT scans and arthroscopy. A difference between CT and arthroscopy of less than 2.0 mm was considered clinically acceptable (dashed lines). The limits of agreement are -1.4 to 2.1 mm.

There was an excellent correlation (r = 0.975; p <0.001) between CT and arthroscopy. There was no statistically significant systematic difference (mean, 0.36 mm, 95% CI, -0.051 to 0.77). Linear regression showed that the relation of CT to arthroscopy was expressed by $y = 1.069x - 0.557$ (Figure 4). There was one subject with a difference of more than 2.0 mm (Figure 5). The limits of agreement were -1.4 to 2.1 mm.

Discussion

This study shows that CT of the ankle in full plantar flexion is an accurate and reliable preoperative planning tool to determine the anterior arthroscopic accessibility of a talar OCD. This is evidenced by the agreement (Figure 5) and correlation (r = 0.975) of CT and anterior ankle arthroscopy with respect to the distance between the OCD and the anterior distal tibial rim. There was only one patient with a difference between CT and arthroscopy greater than 2.0 mm. Furthermore, the formula expressing the relation of CT to arthroscopy approximates a perfect relation of $y = x$ (Figure 4). This scan is now incorporated into routine preoperative planning in our orthopaedic service.

From the location of the OCD, it can be postulated how accessible the defect will be (Figure 4). All OCDs that were located in the anterior or central third of the talar dome were in easy arthroscopic reach, whereas all posterior OCDs were more difficult to access because they were located posteriorly to the anterior distal tibial rim. Because the location of the OCD on the plantarflexion scan corresponds well to the arthroscopic location, the CT scan can be used reliably to predict the arthroscopic reach of the OCD: if the anterior border of the defect is located anteriorly to the anterior distal tibial rim on the plantarflexion scan – which was the case in the anterior lesion and in all but one of the central lesions – the OCD will be accessible through anterior arthroscopy. Even when the OCD is located behind the anterior distal tibial rim with maximal plantar flexion of the ankle, it can often still be reached by anterior arthroscopy. Access in these posterior lesions depends on various parameters, such as ankle range of motion, joint laxity, and the presence of osteophytes, as well as surgical methods. Removal of osteophytes and joint opening in case of ligament laxity will

ease the access. Therefore, general recommendations for doubtful cases – especially posterior lesions – cannot be given. The decision for the most appropriate operative approach in posterior lesions thus remains at the discretion of the surgeon. Nevertheless, the CT scan does provide reliable data on the expected arthroscopic location of the OCD, thus facilitating preoperative planning.

To determine exactly if the scan can differentiate between accessible and inaccessible defects, an additional study would have to be performed in which all plantarflexed scans are judged preoperatively by the surgeon, determining whether it is possible to reach the defect with anterior arthroscopy, and then anterior arthroscopy would be performed in all lesions – even when the surgeon finds this approach inappropriate. Because some patients would undergo a surgical procedure without treatment, this study setup seems unethical. Therefore, the indirect study method was applied as outlined in the paper. With this method, it was shown that the location of the OCDs correlates well between the plantarflexed CT and anterior arthroscopy.

Different surgical methods could be used to improve the exposure if necessary. For example, three patients in the study group had anterior tibial osteophytes. Their removal improved the accessibility of the OCD. Because these osteophytes were shown on CT, they did not interfere with the correlation and agreement between CT and arthroscopy, because all measurements were performed before removal of osteophytes. Likewise, access to the defects located posterior to the anterior distal tibial rim could be improved by removing a small part of the rim using a bonecutter shaver (after measuring the distance of OCD to anterior distal tibial rim with an arthroscopic ruler) or using temporary noninvasive distraction. With noninvasive distraction, the force of distraction was not actually measured in this group, but it was 110 N in OCD patients in a previous study.[428]

The optimal surgical approach depends on the characteristics of the OCD and the patient, the type of treatment, and the experience of the surgeon.[296,408] Anterior arthroscopic ankle surgery is the primary treatment of choice and has the advantages of enhanced visualization, outpatients' treatment, less postoperative morbidity than open surgery, and early functional rehabilitation.[93,348,432]. Alternative approaches are posterior arthroscopy or open surgery with or without a malleolar osteotomy.[296,427,432] Saxena and Eakin treated OCDs arthroscopically when they were located within the anterior 50% of the talar dome.[343] They performed an arthrotomy with or without osteotomy in 13 of the 26 patients who underwent microfracture. Likewise, in a study of 44 patients with 45 OCDs that were initially accessed by anterior ankle arthroscopy, Hankemeier et al. converted to an arthrotomy in 13 and to a medial malleolar osteotomy in 12 because of insufficient access.[179] These patients may have benefitted from more precise preoperative planning.

The intraobserver and interobserver reliability of measurements on CT was excellent. There was no statistically significant intraobserver systematic difference. However, the interobserver systematic difference was 0.37 mm ($p < 0.001$). The source of this difference might have been slight differences in drawing the tangent line of the anterior distal tibial rim, or the level in the ankle joint at which the measurements were made. A level of measurement that is more superior results in a higher distance, because the lines of the anterior OCD and the anterior distal tibial rim cross the talus perpendicularly and are thus divergent (see Figure 3). Though statistically significant, the interobserver difference is so small that it may not be clinically relevant, because 0.37 mm is probably too small to differentiate between an accessible and inaccessible OCD.

Alternatively to CT scans, radiographs might be used to estimate the arthroscopic reach, with the advantages of general availability, less radiation and lower costs. However, talar OCDs are rarely visible on lateral radiographs, and the dimensions are underestimated.[105] Radiographs thus seem to be inappropriate for preoperative planning.

Strengths of this study are the prospective method, the consecutive and representative series of patients, the blinded comparison of arthroscopy and CT, and the clinical relevance. The number of patients, though relatively small, is supported by a power analysis.[443] The study group is diverse and representative for a larger population. The distribution of the OCDs' location in the studied population corresponds to a survey of 428 OCDs in 424 patients.[322] In this survey, 6% of the lesions were located in the anterior third, 81% in the middle third, and 14% in the posterior third, compared with 5%, 70%, and 25%, respectively, in the present study.

There are also limitations. There are inherent differences between CT and arthroscopy. The bony defect was assessed on CT, whereas the articular surface (i.e., the cartilage lesion) was assessed with arthroscopy. Furthermore, the degree of plantar flexion may differ between the CT and arthroscopy because of the effects of anesthesia and the lack of pain. The plantarflexion angle was not investigated with patients under anesthesia. Despite these differences, there was excellent agreement and no significant difference of the distances evaluated by CT and arthroscopy, thus supporting the reliability and usefulness of CT scans.

A disadvantage of the additional CT scan is exposure to radiation. The Committee of Radiation at our hospital has estimated the radiation of the low-dose plantarflexion scan to be 0.02 mSv. This is categorized as a "trivial" risk for average adults by the International Commission on Radiological Protection.[1] The natural background effective dose rate varies considerably from place to place but typically is around 2.4 mSv/yr. The additional radiation of the CT scan can thus be considered acceptable. To reduce the total radiation dose, one may consider acquiring only the plantarflexion CT scan and omitting the plantigrade scan.

Conclusion

Measurements on CT scans of the ankle in full plantar flexion are a reliable and accurate preoperative method to determine the in situ arthroscopic location of talar OCDs.

Acknowledgment

The authors thank I.N. Sierevelt, M.Sc., from the Orthopaedic Research Center Amsterdam, Department of Orthopaedic Surgery, Academic Medical Center, for statistical advice and M. Poulus and M. Schrijnders from the Department of Radiology, Academic Medical Center, for technical support.

Chapter 5

Arthroscopic accessibility of the talus quantified by computed tomography simulation

Christiaan J.A. van Bergen
Gabriëlle J.M. Tuijthof
Mario Maas
Inger N. Sierevelt
C. Niek van Dijk

American Journal of Sports Medicine
2012;40(10):2318-2324.

Abstract

Background

Anterior ankle arthroscopy is the preferred surgical approach for the treatment of osteochondral defects of the talus (OCDs). However, the ankle is a congruent joint with limited surgical access.

Purpose

The dual purpose of this study was (1) to quantify the anterior arthroscopic reach (defined as the proportion of the talar dome articular surface located anterior to the anterior distal tibial rim) with the ankle in full plantar flexion, and (2) to identify predictive factors of the arthroscopic reach.

Methods

Computed tomography scans were obtained of 59 ankles (57 patients aged 33 ± 11 years) in full plantar flexion in a non-metallic 3-dimensional footplate. The arthroscopic reach of both the medial and lateral talar domes was assessed on sagittal reconstructions using a custom-made software routine. Intraobserver and interobserver reliability were calculated by intraclass correlation coefficients (ICCs). Various predictive factors of the arthroscopic reach were analyzed by multivariate linear regression analysis.

Results

The arthroscopic reach was 48.2% ± 6.7% (range, 26.7% – 60.7%) of the medial talar dome and 47.8% ± 6.5% (range, 31.2% – 65.1%) of the lateral talar dome ($p = 0.62$). The intraobserver and interobserver reliability of both measurements were excellent (ICC, 0.99). The clinical plantarflexion angle was a statistically significant predictive factor of both the medial and lateral arthroscopic reaches (i.e., increased plantar flexion corresponded to increased area of access), while joint laxity, gender, and age were not predictive.

Conclusions

Almost half of the talar dome is accessible anterior to the anterior distal tibial rim. The plantarflexion angle is an independent predictive factor of the arthroscopic reach both medially and laterally.

Clinical Relevance

These results may facilitate preoperative planning of the surgical approach for OCDs.

Introduction

Osteochondral defects of the talus (OCDs) typically affect young, active adults. The location of OCDs has been described classically as posteromedial or anterolateral.[49,135] More recently, a large survey of more than 400 patients showed that these defects are most frequently located on the middle third of the medial or lateral talar dome in a nine-grid scheme.[322] Arthroscopic debridement and bone marrow stimulation is considered the primary surgical treatment.[153,458] Most OCDs can be reached and treated through anterior ankle arthroscopy.[432] During this procedure, access to the talar dome is restricted by the tibial plafond due to the high congruence of the ankle joint. Therefore, the OCD is treated in the anterior working area with full plantar flexion of the ankle (Figure 1). However, whether the OCD can be reached by anterior ankle arthroscopy may often be unclear preoperatively.

As a rule of thumb, OCDs located in the anterior half, including the anterior part of the posterior half of the talus, can be reached and treated by anterior ankle arthroscopy in patients with unlimited plantar flexion.[432] After identification of the OCD with the ankle in full plantar flexion, the defect is debrided anteriorly to posteriorly, thus gaining further access during arthroscopic treatment. Saxena and Eakin approached OCDs arthroscopically when they were located within the anterior 50% of the talar dome, while an arthrotomy with or without osteotomy was performed for defects located in the posterior half. [343] Similarly, Gobbi et al. withheld patients with far posterior or central lesions from arthroscopic management.[156] Hankemeier et al. converted from arthroscopy to arthrotomy, with or without a medial malleolar osteotomy, in 25 of 45 ankles because of insufficient access to the OCD.[179] Preoperative knowledge of arthroscopic reach of the talus may facilitate the choice of surgical approach for talar OCDs.

For preoperative planning, computed tomography (CT) scans accurately assess the size and extent of the bony lesion.[129,160] The range of motion of the ankle joint has been successfully analyzed using stress CT with forced extreme positions in healthy individuals.[402] Using a similar scanning technique in patients with an OCD, van Bergen et al. showed that the location of talar OCDs on CT scans of the ankle in full

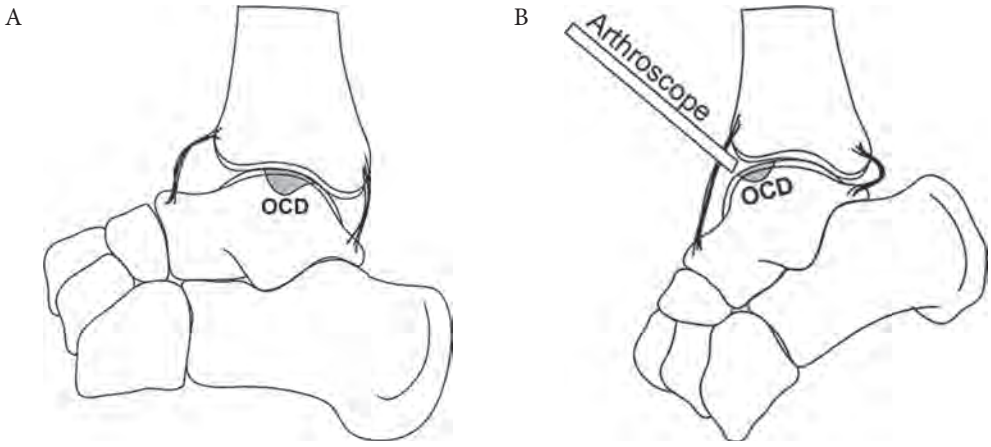


Figure 1. Schematic drawing showing the effect of plantar flexion on the arthroscopic reach of an osteochondral defect of the talus (OCD). In the neutral (plantigrade) ankle position, the OCD is covered by the tibial plafond (A). In full plantar flexion, the OCD can be accessed in the anterior arthroscopic working area (B).

plantar flexion corresponded well with the in situ intraoperative arthroscopic findings of the OCDs.[415] Hence, a CT scan of the ankle in full plantar flexion can be used reliably to determine the reach of OCDs with anterior ankle arthroscopy. However, this scanning technique is not readily available in most places. Normal values of arthroscopic reach could thus be helpful for the planning of treatment. Identifying predictive factors of the arthroscopic reach may further improve the preoperative planning process.

The dual purpose of this study was (1) to simulate and quantify, with the use of CT data, the area of the talar dome that can be accessed anteriorly to the anterior distal tibial rim (i.e., arthroscopic reach) with the ankle in full plantar flexion, and (2) to identify predictive factors of the arthroscopic reach. We hypothesized that (1) 50% of the talar dome articular surface is located anteriorly to the anterior distal tibial rim, and (2) plantarflexion angle and joint laxity (anterior drawer test) are independent predictive factors of the arthroscopic reach.

Materials and methods

A prospective study was undertaken according to a study protocol approved by the local Medical Ethics Committee. Fifty-seven patients, aged 18 years or older (mean age, 33 ± 11 years), with a known or suspected OCD in 59 ankles (32 right, 27 left) were included between May 2008 and June 2010, including 20 patients from a previous validation study.[415] In two patients, both ankles were scanned because of a bilateral OCD. There

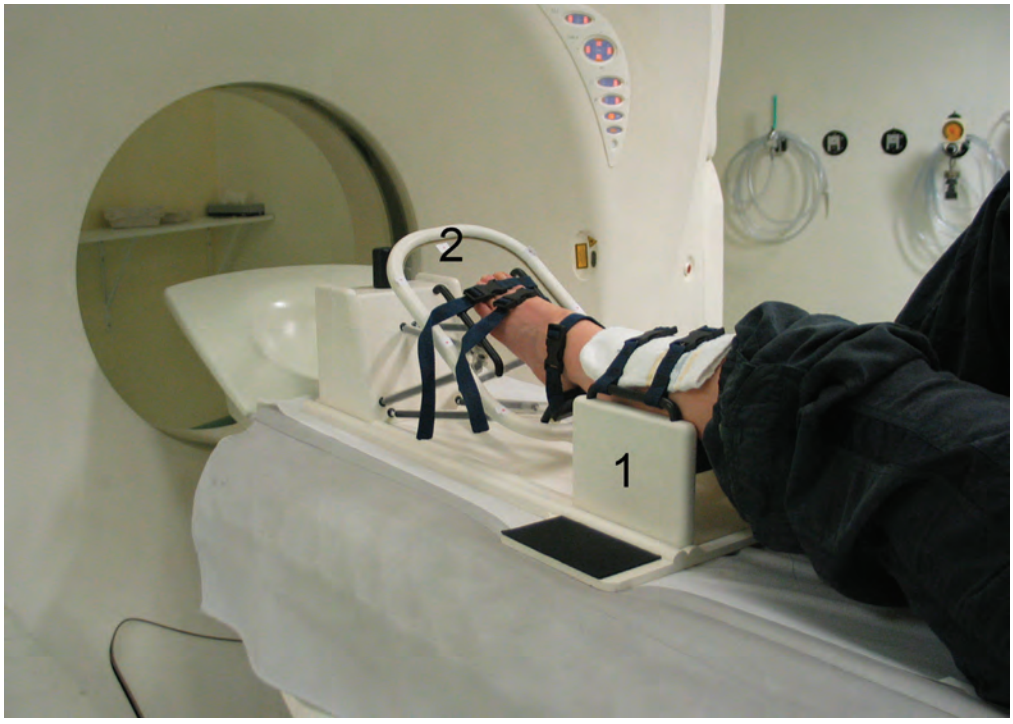


Figure 2. Computed tomography (CT) scanning of an ankle in full plantar flexion using a 3-dimensional footplate. The patient was positioned on the CT table with the affected lower leg attached to the supporting base platform (1) and the foot attached to the footplate (2). The ankle was forced into full plantar flexion and the footplate secured.

were 44 male and 13 female patients. Informed consent was obtained.

Computed tomography

A multislice helical CT scan was acquired of each affected ankle in full plantar flexion (Figure 2). A non-metallic 3-dimensional (3-D) footplate (unpublished data, 2011) compatible with CT scanning was constructed to fit into a commercial CT scanner (Figure 2). The 3-D footplate had six degrees of freedom and allowed unconstrained hindfoot joint motion upon loading to force the foot in an extreme position. The patient lay supine on the CT table, and the affected lower leg was fixed to a base platform of the 3-D footplate with two straps. The base platform was 10 cm above the CT table, allowing slight flexion of the knee and relaxation of the gastrocnemius muscle. The foot was attached to the 3-D footplate, and the ankle was positioned in full plantar flexion and secured by turning the fixation handle.

Analogous to the protocol as described previously,[46] a Philips MX8000 spiral CT scanner (Philips Medical Systems, Eindhoven, the Netherlands) was used with the following settings: tube voltage, 120 kV; tube current, 26 mAs; collimation, 2 × 0.5 mm; slice thickness, 0.6 mm; slice increment, 0.3 mm; voxel size, 0.3 × 0.3 × 0.3 mm; image matrix, 512 × 512 pixels; rotation time, 0.75 s; resolution, ultra high; kernel, D (sharp); and gantry tilt, 0. The examined volume included the distal tibia and the complete talus. The Committee of Radiation of our hospital has estimated the radiation of the scan to be 0.02 mSv, which is categorized as a "trivial" risk for average adults by the International Commission on Radiological Protection.[1]

The original axial images were reformatted into sagittal 1.0-mm slices in two planes: one set of images parallel to the medial talar facet and one set parallel to the lateral talar facet. These planes were defined to correspond with the geometry of the talar dome, which has a divergent anatomic orientation.[205] The reformatted images parallel to the medial talar facet were used for the assessment of the medial talar dome, while the images parallel to the lateral facet were used for the lateral talar dome.

Outcome analysis

Arthroscopic reach was defined as the proportion of the talar dome articular surface located anteriorly to the anterior distal tibial rim.[415] This definition was based on the fact that, initially during arthroscopy, only the anterior part of the lesion has to be identified. The OCD is then treated anteriorly to posteriorly, thus gaining further exposure during treatment. Removal of the anterior part of the cartilage lesion creates more space for access to the more posterior defect area. The ankle joint opens up anteriorly by forced plantar flexion, improving access to the complete defect.

To determine the arthroscopic reach, we made the following measurements (Figure 3). The anterior and posterior borders of the talar dome and the anterior distal tibial rim were digitally marked on medial and lateral sagittal reconstructions using the radiology Picture Archiving and Communication System (Impax 5.3.1, Agfa-Gevaert NV, Mortsel, Belgium), providing two measurements for each scan. In case of a clear anterior distal tibial osteophyte (i.e., fully sclerosed relevant extension of the anterior rim), the osteophyte was excluded from analysis because it is usually removed when performing ankle arthroscopy for OCDs.[346] The marked CT images were loaded into a custom-made software routine (Matlab, version 7.5.0.342 (R2007b), The Mathworks, Natick, Massachusetts). Within this routine, two observers independently indicated the talar dome contour with 10 points. Based on these data, two angles, α and β, were

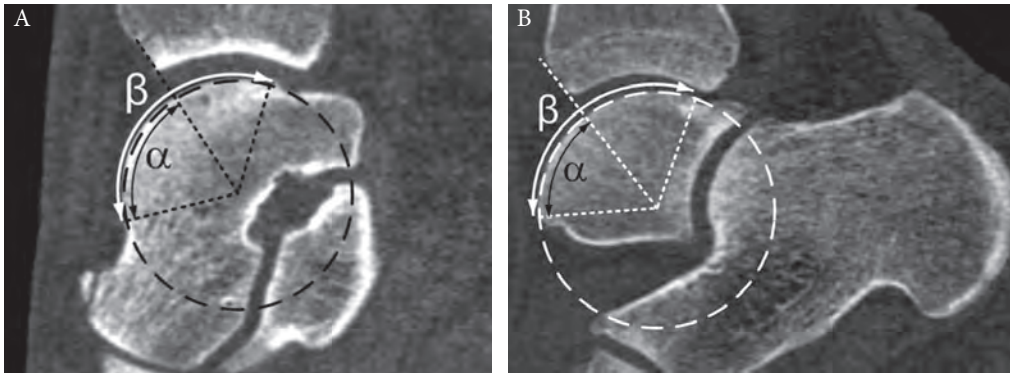


Figure 3. Sagittal computed tomography reconstructions of a fully plantarflexed ankle showing the measurements performed to assess the arthroscopic reach of the medial (A) and lateral (B) talar domes. Using a custom-made software routine, a circle was fit through the talar articular surface. Angle α (black arrow, i.e., area anterior to the distal tibial rim) was defined by the arc length of the circle between the dashed lines from the midpoint of the circle to the anterior border of the talar dome and to the anterior distal tibial rim, respectively, divided by the total circle's circumference. Angle β (white arrow, i.e., complete talar dome) was defined by the arc length of the circle between the dashed lines from the midpoint to the anterior border of the talar dome and to the posterior border of the talar dome, respectively, divided by the total circle's circumference. The arthroscopic reach (%) was calculated by dividing angle α by angle β times 100%.

calculated as follows. A circle was fit through the 10 points on the talar dome using a least squares algorithm, providing the circle's diameter and midpoint coordinates. The latter was used as the imaginary center of rotation of the ankle joint.[266] Subsequently, angle α was calculated as the arc length of the circle between the line crossing the anterior border of the talar dome and the midpoint, and the line crossing the anterior distal tibial rim and the midpoint, divided by the total circle's circumference (Figure 3). Analogously, angle β was calculated as the arc length of the circle between the line crossing the anterior border of the talar dome and the midpoint, and the line crossing the posterior border of the talar dome and the midpoint, divided by the total circle's circumference (Figure 3). Finally, the accessible area (%) of the talar dome was calculated by dividing angle α (indicating the anterior area) by angle β (indicating the complete talar dome). To assess intraobserver reliability, this complete process was repeated by one of the observers, in different order of scans and blinded to the first sequence.

Predictive factors

To investigate the hypothesis that increased plantar flexion and joint laxity improve the arthroscopic reach, these factors were assessed prior to CT scanning in 46 ankles. The other predictors investigated were gender and age.

The passive plantarflexion angle was measured from a lateral view with a goniometer, using the anterior side of the lower leg and dorsum of the foot as landmarks (Figure 4). The measured angles were divided into three groups: group 1 (n = 6), plantarflexion angle >180°; group 2 (n = 18), plantarflexion angle 171° - 180°; and group 3 (n = 22), plantarflexion angle ≤170°. These cutoff values were based on our clinical experience that more than 180° indicates increased range of motion, while less than 170° indicates restriction in range of motion.

The anterior drawer test was performed to assess joint laxity. The assessor determined the amount of force and estimated the excursion. A positive test (n = 9) was defined as an anterior drawer of ≥4 mm and/or a difference between left and right of >2 mm.[423]

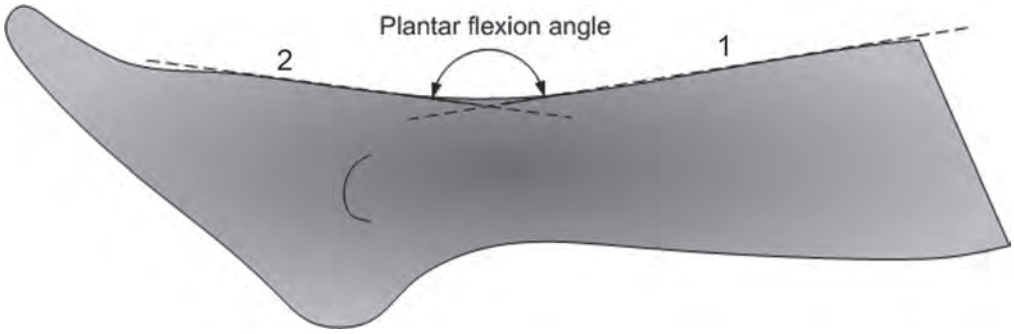


Figure 4. Schematic view of a lower leg. The clinical plantarflexion angle was measured with the anterior side of the lower leg (1) and dorsum of the foot (2) as landmarks.

Statistical analysis

The mean of both observers' first CT measurements is reported. The continuous data (age, angles α and β, and arthroscopic reach) were normally distributed and are presented as mean ± standard deviation, supplemented with 95% confidence intervals (CIs) and ranges for the arthroscopic reach of the talar dome. The statistical difference between the arthroscopic reach of the medial and lateral talar domes was calculated with the paired t-test. The intraobserver and interobserver reliability of the arthroscopic reach were analyzed using intraclass correlation coefficients (ICCs). According to Fleiss, the reliability is considered excellent if the ICC is >0.75.[134]

To identify predictive factors of the arthroscopic reach, multivariate linear regression analysis was performed with a backward selection procedure. The dependent variables were the medial and lateral arthroscopic reaches. The investigated independent variables were plantarflexion angle, anterior drawer test, gender, and age. Plantarflexion angle was a categorical variable with three groups. Each independent variable was initially tested by use of univariate analyses. Those variables significantly associated with arthroscopic reach (significance level, 0.10) were entered in the multivariate regression analysis. The unstandardized regression coefficient (B) and standard error (SE) were calculated. A p-value of 0.05 indicated statistical significance.

Results

On the medial talar dome, angle α was 51.2° ± 10.5°, and angle β was 106.2° ± 14.9°, resulting in an arthroscopic reach of 48.2% ± 6.7% (95% CI, 46.4% – 49.9%; range, 26.7% – 60.7%) (Figure 5A). On the lateral talar dome, angle α was 49.3° ± 8.3°, and angle β was 103.1° ± 11.5°, indicating an arthroscopic reach of 47.8% ± 6.5% (95% CI, 46.1% – 49.5%; range, 31.2% – 65.1%) (Figure 5B). The difference between medial and lateral was not statistically significant (p = 0.62). The intraobserver and interobserver reliability of the measured angles on CT were excellent (both ICCs, 0.99; p < 0.001).

On the medial talar dome, the arthroscopic reach was 52.6% ± 6.1% in plantarflexion group 1 (>180°), 50.8% ± 5.7% in group 2 (171° - 180°), and 45.5% ± 4.8% in group 3 (≤170°) (Figure 6). On the lateral talar dome, the arthroscopic reach was 53.7% ± 8.7%, 49.2% ± 3.7%, and 45.4% ± 6.0% in plantarflexion groups 1, 2, and 3, respectively.

With the medial arthroscopic reach as the dependent variable, univariate analysis revealed three significant factors (plantarflexion angle, gender, and age) to be included in

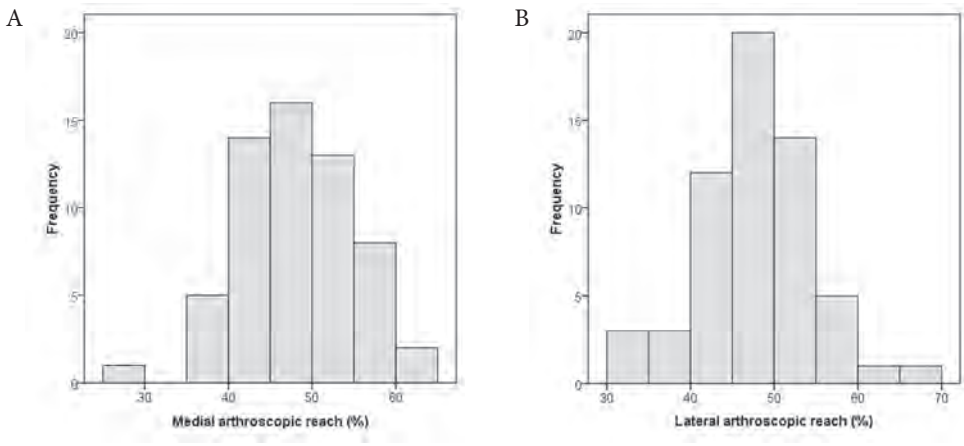


Figure 5. Histogram showing the distribution of the measured arthroscopic reach of the medial (A) and lateral (B) talar domes in the study population.

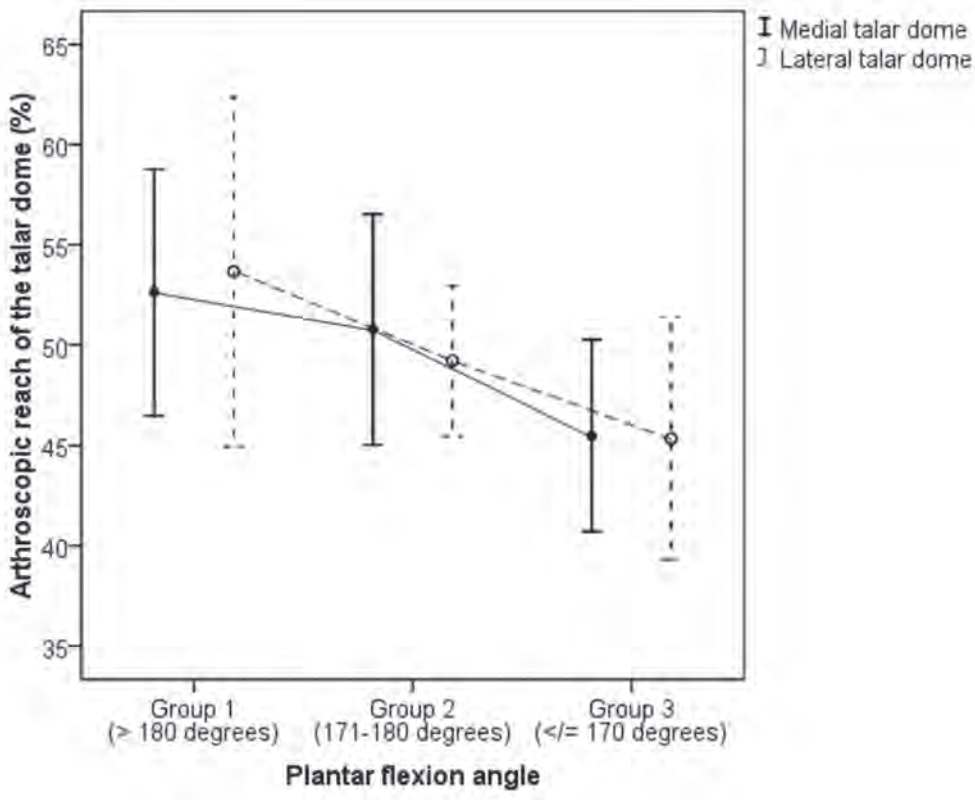


Figure 6. Arthroscopic reach (mean and standard deviation) of the medial (continuous line) and lateral (dashed line) talar domes in three patient groups with different plantarflexion angles. The clinical plantarflexion angle was a significant, independent predictor of the arthroscopic reach.

the multivariate linear regression analysis. Multivariate analysis revealed only the plantarflexion angle as a predictive factor of the medial arthroscopic reach (group 1 vs. group 3: p = 0.02, B = 6.7, SE = 2.7; group 2 vs. group 3: p = 0.03, B = 4.0, SE = 1.8).

Univariate analysis showed that two factors (plantarflexion angle and age) were significantly associated with the lateral arthroscopic reach. Multivariate linear regression analysis showed that only the plantarflexion angle was significantly associated with the lateral arthroscopic reach (group 1 vs. group 3: p = 0.01, B = 7.6, SE = 2.7; group 2 vs. group 3: p = 0.09, B = 3.1, SE 1.8). The other investigated factors did not reach statistical significance in the multivariate analyses.

Discussion

This study aimed to quantify the anterior arthroscopic reach of the talar dome. It is shown that almost half (48%) of the articular surface of the talar dome is situated anteriorly to the tibial plafond with the ankle joint in full plantar flexion. Thus, on average, an OCD can be reached and treated by anterior ankle arthroscopy if its anterior border is located in the anterior half of the talar dome. The anterior defect border is the landmark for accessibility, since only this part of the defect has to be identified initially during arthroscopy. The defect is then treated anteriorly to posteriorly, thus gaining further exposure during treatment. As the plantarflexion angle is an independent predictor of arthroscopic reach, the preoperative estimation of exposure can be improved by measuring the plantarflexion angle clinically. These findings can serve as a guideline for preoperative planning of the surgical approach.

Exposure of the talus has been quantified in studies with different open surgical approaches. Muir et al. compared seven approaches, including four arthrotomies (anteromedial, anterolateral, posteromedial, and posterolateral) and three osteotomies (anterolateral tibial plafond, distal fibula, and medial malleolus) in nine cadaver specimens.[293] After Kirschner wires had been inserted in the talus through the different approaches, lateral radiographs were used to measure sagittal access. Using an anteromedial arthrotomy, they could access a mean of 47% (range, 41% - 60%) of the medial talar dome in the sagittal plane. The anterolateral arthrotomy provided 43% (range, 37% - 50%) sagittal access of the lateral talar dome. Young et al. have presented data on cadaveric dissections of five ankles to evaluate the accessible region of the medial talar dome through an anteromedial and posteromedial open approach without osteotomy.[456] They found that a median of 50% (range, 44% - 58%) of the anteroposterior medial talar dome length could be reached through the anteromedial approach. The results of our study are in the range of the findings of both cadaveric studies. The added value of the present study is the use of a validated method,[415] specific focus on arthroscopy, the larger and representative study population, and the identification of predictive factors of arthroscopic reach. The results may also be relevant for osteochondral grafting or other methods that require perpendicular access to the OCD. However, in these cases, the posterior border of the OCD (instead of the anterior border) has to be located anteriorly to the anterior distal tibial rim for complete access.

The importance of plantar flexion on the exposure of the talus by anterior ankle arthroscopy can be estimated when comparing the CT angles of this study with radiographic angles of another study. Magerkurth and colleagues published normal values of hindfoot dimensions in a series of 100 radiographs of neutrally positioned ankles.[266] They found that the mean angle of talar coverage by the tibia,

defined by the center of the talus and the borders of the distal tibial joint plane, was 88.1°. In our study, the complete talar dome angle (β) was 104.6° (i.e., mean of medial and lateral). This suggests that only 15.8% (i.e., (104.6° - 88.1°)/104.6° × 100%) of the talar dome articular surface is uncovered by the tibial plafond when the ankle is in a plantigrade position. Our study shows that 48% of the talar dome is uncovered when the ankle is in full plantar flexion, suggesting that this area is increased threefold. However, this calculation should be interpreted with caution because different diagnostic modalities were used (i.e., plain radiographs by Magerkurth et al. vs. CT by us).

Numerous diagnostic methods are in use for talar OCDs, including plain radiographs, CT, magnetic resonance imaging (MRI), and, more recently, single-photon emission computed tomography (SPECT-CT).[246,440] Verhagen et al. showed that MRI and multislice helical CT have similar diagnostic accuracy that are both superior to plain radiographs.[440] MRI may further show concomitant soft-tissue injury. The diagnostic value of SPECT-CT has not been reported, but its use has led to a treatment decision making change in 48% compared with MRI. The use of either CT or MRI is recommended for the diagnosis of OCD, but as the subchondral bony defect is the main problem in ankle lesions,[434] CT scans are preferred for preoperative planning because they accurately assess the size of the bony fragment or associated cyst.[129,160]

With anterior ankle arthroscopy, vision of only the anterior part of the OCD is initially required.[432] After identification of the anterior border of the defect, it is debrided anteriorly to posteriorly to further expose the defect, followed by microfracturing.[432] We routinely use a 4.0-mm, 30° angle arthroscope, a 4.5-mm or 5.5-mm bonecutter shaver, and a 45° angle microfracture awl. An angled microfracture awl allows treating a lesion "around the corner."

If access is insufficient with the standard anterior arthroscopy procedure, there are some alternative arthroscopic approaches. The anterior portals can be combined with a posterolateral portal.[129,341] Alternatively, a two-portal hindfoot arthroscopic approach with the patient in the prone position is applied to treat OCDs located far posteriorly.[432] However, these procedures require more experience. Furthermore, distraction of the ankle joint can be used to improve exposure in ankle arthroscopy.[129] For example, Kelberine and Frank in 1999 described 48 ankle arthroscopies for the treatment of OCDs.[210] To gain access to the lesions, distraction was used in 11 patients, and an additional posterolateral portal was made in one patient.[210] The maximum joint distraction has been reported to average 1.3 to 4.5 mm.[108,428] Continuous distraction, however, could possibly lead to more neurovascular complications.[96,108] We prefer an anterior arthroscopy technique without continuous distraction, applying dorsiflexion and plantar flexion as indicated and, if necessary, temporary noninvasive distraction.[432] Alternatives to microfracturing or antegrade drilling for hardly accessible lesions are transmalleolar or retrograde drilling.[228,378] Although good clinical results have been reported, there are disadvantages of both techniques that are not encountered with microfracturing or antegrade drilling. With transmalleolar drilling, healthy tibial cartilage is sacrificed. Retrograde drilling requires intact overlying cartilage of the OCD and is therefore only occasionally applicable.

The present study has limitations. According to the findings of this study, a mean of 48% of the talar articular surface is accessible in the anterior arthroscopic working area. These findings can provide clear clinical guidelines for the optimal surgical approach. However, the percentages reported might be rather strict, as there are different surgical methods to improve exposure, including grooving of the anterior

distal tibial rim and using temporary noninvasive distraction.[135,432] These surgical methods were not assessed in this study. Nevertheless, the data can be regarded as the lower limit of access, which can further be improved in practice, thus being on the safe side. Furthermore, there was a high range of arthroscopic reach, that is, 27% to 61% on the medial side and 31% to 65% on the lateral side. Because of this range, a CT scan of the ankle in full plantar flexion is advised for doubtful cases to optimize the preoperative planning individually. Another possible limitation is that arthroscopic reach was assessed indirectly with CT scans rather than with arthroscopy. For arthroscopic assessment, cadaveric ankles would have to be used, but these are not representative of the patient population and are scarce. The obtained results can be regarded as reliable because the methods used were validated in a previous study.[415] Finally, different physicians assessed a subset of ankles (46 of 59) for clinical plantar flexion and joint laxity. These assessments may be subject to interobserver variability. The variability was minimized by providing clear instructions for measurements, and using easily recognizable anatomic landmarks for clinical plantarflexion measurement. The interobserver reliability of plantarflexion measurement in another study was good (ICC, 0.72), although the measurement technique in that study was not specifically described.[119] Although clinical plantar flexion was an independent predictor of the arthroscopic reach (Figure 6), joint laxity, in contrast to our hypothesis, was not. Therefore, the arthroscopic reach variability cannot be reliably correlated with ankle laxity.

Conclusion

This study quantifies the anterior arthroscopic reach of the talus with CT scans in a representative patient population. With the ankle in full plantar flexion, a mean of 48% of the talar dome, both medial and lateral, is located anteriorly to the anterior distal tibial rim. The clinical plantarflexion angle is an independent predictor of the arthroscopic reach. These results facilitate preoperative planning of the surgical approach for treatment of OCDs.

Acknowledgment

The authors thank Mr. M. Poulus from the Department of Radiology, Academic Medical Center Amsterdam, for technical support with CT scanning and reformatting.

Chapter 6

Arthroscopic treatment of osteochondral defects of the talus: outcomes after 8 to 20 years of follow-up

Christiaan J.A. van Bergen
Laura S. Kox
Mario Maas
Inger N. Sierevelt
Gino M.M.J. Kerkhoffs
C. Niek van Dijk

The Journal of Bone & Joint Surgery (American volume)
2013;95(6):519-525.

Abstract

Background

The primary aim of this study was to assess the long-term clinical and radiographic outcomes of arthroscopic debridement and bone marrow stimulation for talar osteochondral defects. The secondary aim was to identify prognostic factors that affect the long-term results.

Methods

Fifty (88%) of 57 eligible patients with a primary osteochondral defect treated by arthroscopic debridement and bone marrow stimulation were evaluated after a mean follow-up of 12 years (range, 8 – 20 years). Clinical assessment included the Ogilvie-Harris score, Berndt and Harty outcome question, American Orthopaedic Foot and Ankle Society (AOFAS) ankle-hindfoot score, and Short Form 36 (SF-36), as well as resumption of work and sports. Weight-bearing radiographs were compared with preoperative radiographs with use of an ankle osteoarthritis classification. The size, location, and classification of the defect, patient age and body mass index, traumatic etiology, and duration of symptoms were recorded and analyzed with use of univariate logistic regression.

Results

The Ogilvie-Harris score was excellent in 20% of patients, good in 58%, fair in 22%, and poor in 0%. According to the Berndt and Harty outcome question, 74% of patients rated the ankle as good, 20% as fair and 6% as poor. The median AOFAS score was 88 (range, 64 – 100). Of the eight subscales of the SF-36, six were comparable with population norms and two were superior in the study group. Ninety-four percent of patients had resumed work and 88% had resumed sports. The radiographs indicated an osteoarthritis grade of 0 in 33% of the patients, I in 63%, II in 4%, and III in 0%. Compared with the preoperative osteoarthritis classification, 67% of radiographs showed no progression and 33% showed progression by one grade. None of the prognostic factors was significantly associated with the Ogilvie-Harris score or progression of osteoarthritis.

Conclusions

This study suggests that initial success rates of arthroscopic debridement and bone marrow stimulation for osteochondral defects of the talus are maintained over time. No factors that were predictive of the outcome could be identified.

Introduction

Patients presenting with an osteochondral defect (OCD) of the talus are typically young, active adults with deep ankle pain during or after activity. Other symptoms may include stiffness, swelling, and sometimes a locking sensation of the ankle. The natural course of degenerative joint disease following an OCD has not been well defined, although subchondral cysts may

form and osteoarthritis could be a long-term sequela.[69,433]

Arthroscopic debridement and bone marrow stimulation is considered the gold standard for treatment of primary talar OCDs, with 85% good or excellent results.[458] During this procedure, any loose fragments are removed and the defect is debrided; in addition, small holes in the underlying subchondral bone can be made by drilling or puncturing to promote revascularization. There are concerns that the fibrocartilaginous tissue formed after bone marrow stimulation may be insufficient in the long term because it does not have the same biomechanical properties as native hyaline cartilage.[229,262]

The authors of previous studies have attempted to identify prognostic factors associated with such treatment. Such factors included defect size, patient age, body mass index (BMI), history of trauma, and duration of symptoms. Of these factors, the size of the defect appeared to be the most consistently associated with the clinical outcome.[76,77,82,156,165]

The goals of the present study were to evaluate the long-term outcome of arthroscopic debridement and bone marrow stimulation for OCDs of the talus and to identify prognostic factors that affect the outcome.

Methods

This study was approved by the local Medical Ethics Committee. We identified 105 patients who had undergone arthroscopic treatment of a talar OCD from 1988 to 2000. On the basis of the inclusion and exclusion criteria, 57 patients who had undergone arthroscopic treatment of a primary OCD were invited to participate in the study (Figure 1). The stages of the invitation process consisted of mailing a letter (accompanied by a prepaid envelope) requesting permission to telephone the patient, making an appointment for a follow-up visit at the hospital, and mailing the patient information, informed consent forms, and questionnaires 1 week in advance of the follow-up visit. Fifty (88%) of the eligible patients provided informed consent and were included. Two of these patients did not consent to visit the hospital but completed the questionnaires by mail. Fourteen of the patients included in this study had been evaluated 9 years previously.[346] They were reevaluated as a prospective cohort to determine whether their outcomes had deteriorated with time.

Patient evaluation included a chart review, interview, physical examination, and radiographic evaluation. One author not involved in the surgical procedures assessed the patients and completed custom-designed case report forms. The completed case report forms were entered into a digital database with use of custom-designed digital data entry sheets.

The data retrieved from the charts and interview included the trauma mechanism, duration of ankle symptoms before surgery, postoperative rehabilitation, any additional surgery, pain, stiffness, swelling, and function. The physical examination performed at the follow-up visit included weight and height, gait pattern, hindfoot alignment, swelling, ankle motion and stiffness, muscle function, stability, sensibility, and tenderness. Special attention was paid to the possibility of neurovascular complications.

Clinical outcome measures

The primary outcome measure was the subjective outcome of the patients as assessed with use of the Ogilvie-Harris score.[304] Secondary clinical outcome measures were the Berndt and Harty outcome question,[49,190] American Orthopaedic Foot & Ankle Society (AOFAS) ankle-hindfoot score,[217] Short Form-36 (SF-36),[7] and resumption of work and sports.

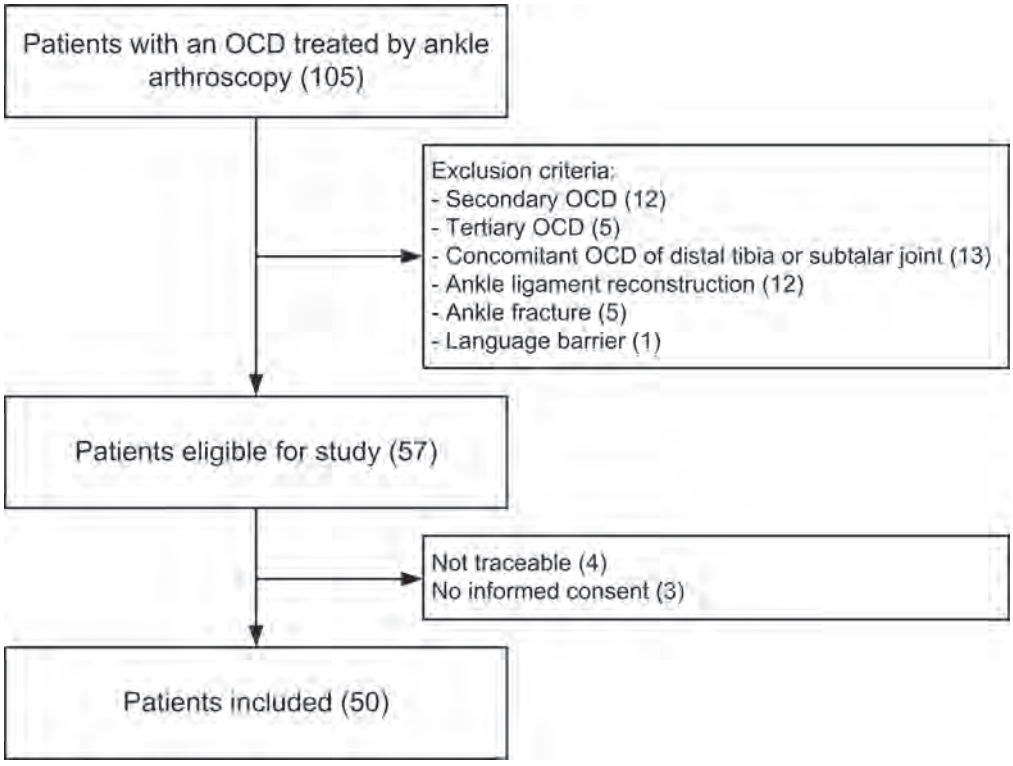


Figure 1. Flowchart showing the inclusion and exclusion of patients. The values in parentheses indicate the number of patients. OCD = osteochondral defect.

The Ogilvie-Harris instrument consists of five items: pain, swelling, stiffness, limping and activity.[304] Each item is rated as excellent, good, fair, or poor. The lowest grade among the items determines the final score. The Ogilvie-Harris score has not been validated but was chosen because of its previous use and the importance of subjective outcome scores in clinical evaluation. The Berndt and Harty outcome question is a single question with three possible answers; the patient categorizes the ankle as good, fair, or poor.[49] The modification introduced in 2003 was used because the original language was confusing.[190] In this modification, patients with a "good" outcome report that they either (1) have no symptoms of pain, swelling, or instability, or (2) experience slightly annoying, but not disabling, symptoms; patients with a "fair" outcome report that the symptoms are somewhat improved but some measure of disability remains; and patients with a "poor" outcome report that, although there are some periods of time without symptoms, the overall symptoms remain unchanged.[190] The AOFAS ankle-hindfoot instrument is a combined objective and subjective clinical rating system.[217] The subjective part has been validated.[192] The AOFAS score can range from 1 to 100 points and is subdivided into pain (40 points), function (50 points) and alignment (10 points), with a score of 100 indicating the best outcome. The SF-36 is a widely used and validated instrument for measuring general health.[7] It consists of eight subscales with a total of 36 items. All instruments used in the

present study have been used in previously published studies evaluating the outcome of OCDs of the ankle.[128,152,190,346]

Imaging

The original size of the defects was assessed on preoperative images. Computed tomography (CT) was the first-choice imaging modality for measuring the size of the OCD and was used in 26 patients. If CT scans were unavailable, the defect size was measured with use of magnetic resonance imaging (MRI) (used in three patients) or conventional radiography. CT is preferred for the assessment of the preoperative size of talar OCDs,[160,282] whereas plain radiographs are less reliable.[105] The authors have used CT routinely since 1993. The MRI scans were acquired in referring hospitals. The defect location was assessed with use of a grid consisting of nine squares.[322] The preoperative OCD condition was rated according to an extended version of the Berndt and Harty radiographic staging system.[49] On the original scale, defects are divided into four stages (I to IV) according to the amount of detachment and displacement of the osteochondral fragment. The addition of a stage V by Scranton and McDermott was used to classify cystic defects.[349] An independent musculoskeletal radiologist who was blinded to the outcome interpreted the imaging studies.

At the final follow-up visit, weight-bearing ankle radiographs were obtained in three directions: anteroposterior mortise, heel rise mortise, and lateral views.[440] The presence of a remaining OCD was assessed in each radiograph by the radiologist.

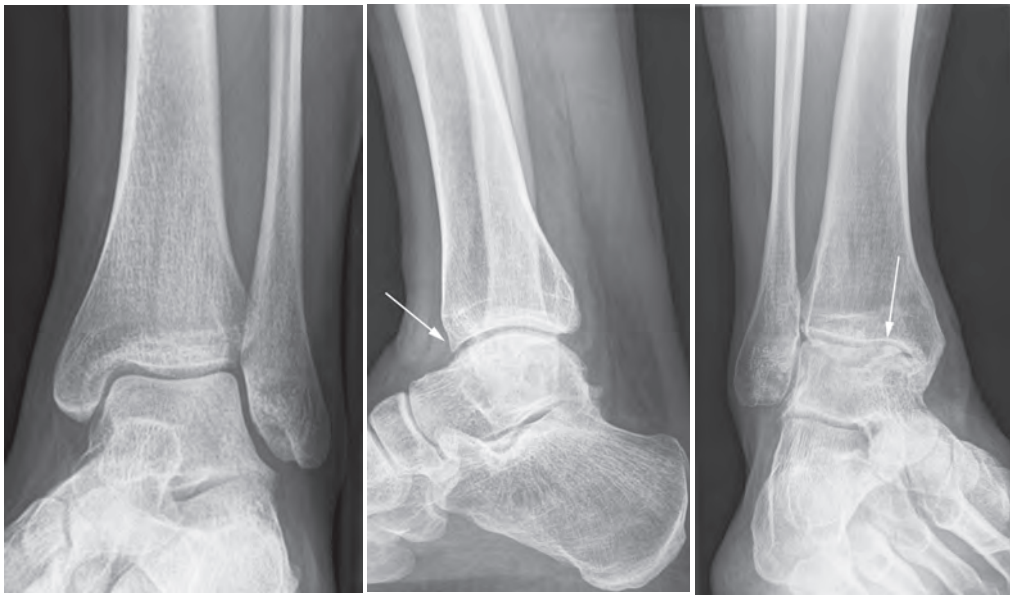
The extent of degenerative change was determined by comparison of the final radiographs with the preoperative radiographs (in 46 cases) or with the first postoperative radiographs (in two cases). All radiographs were digitalized and graded independently in a blinded fashion and random order by two orthopaedic surgeons with use of an ankle osteoarthritis (OA) classification system (Figure 2).[425] In the event of disagreement between the observers, the definite classification was determined independently by the first author in the same blinded, random fashion. Although CT scans are more accurate for the visualization of the OCDs, radiographs were obtained at the final follow-up visit to allow grading of the OA and comparison with previous studies.

Arthroscopic procedures

All arthroscopic procedures were outpatient surgical procedures utilizing an anterior or posterior two-portal approach.[432] The reason for the posterior approach used in three patients was the location of the defect. The anterior approach was performed with the patient in the supine position and the posterior approach was performed with the patient prone.

A local synovectomy was performed in the event of synovitis. Any anterior osteophytes (in 12 patients) or posterior osteophytes (in one patient) were removed. The OCD was identified, and the unstable cartilage and subchondral necrotic bone were removed with a shaver or curette. Full debridement of the sclerotic zone was performed. If the entire base of the defect was bleeding after release of the tourniquet, no additional drilling was used (in 11 patients). In 39 patients (see Table 1), the base of the OCD was additionally penetrated with multiple drill holes with use of a 1.4-mm Kirshner wire or 2-mm drill through the portal. None of the patients received additional bone-grafting.

Active ankle motion exercises were started 2 days postoperatively after removal of the compression bandage. Full dorsiflexion and plantar flexion were encouraged. Partial or non-weight bearing was prescribed for 2 to 8 weeks. No boot, cast, or splint was used.



A B C

Figure 2. Examples of grades 0, I, and II of the ankle osteoarthritis classification system.[425] (Grade III indicates [sub] total disappearance or deformation of the joint space; this was not seen in the study group.) Grade 0, normal joint or subchondral sclerosis (A). Grade I, osteophyte (arrow) without joint space narrowing (B). Grade II, joint space narrowing (arrow) with or without osteophytes (C).

Statistical methods

Statistical analyses were performed with use of SPSS software (version 16.0; Chicago, Illinois). Variables with a normal distribution are presented as the mean and standard deviation. Variables with a skewed distribution are presented as the median and range. The SF-36 subscales were compared with the Dutch population normative data using the Student's t-test.[7] The ages of patients who did and did not resume work and the ages of patients who did and did not resume sport were compared with use of the Mann-Whitney U test. The X^2 test was used to compare progression of OA between patients with cystic and noncystic defects and to compare the Ogilvie-Harris score among different defect locations. The clinical results of the prospective cohort of 14 patients reported previously were analyzed with use of the Wilcoxon signed-rank test.

The relationships of various prognostic factors to the clinical outcome and to OA progression were calculated with use of univariate logistic regression analyses. Specifically, the Ogilvie-Harris score (dichotomized into excellent to good and fair to poor) and progression of the OA classification were compared with the defect size, location, and classification; patient sex, age, and BMI; affected side; traumatic etiology; duration of symptoms; preoperative OA; type of treatment; and duration of follow-up. The BMI at the time of follow-up was used because the preoperative BMI was unavailable. All continuous prognostic factors were analyzed as continuous variables. In addition, several continuous factors were dichotomized on the basis of information in the literature.[44,235,334,457] Specifically, defect size was dichotomized as ≤11 and >11 mm; age, as ≤32 years and >32 years; duration of symptoms, as ≤12 months and >12

months; and BMI, as ≤25 and >25 kg/m^2. The odds ratio (OR) and accompanying 95% confidence interval (CI) were calculated for each prognostic factor. A p-value of <0.05 was considered significant.

Results

The study group consisted of 30 male and 20 female patients (Table 1). The mean age at the time of surgery was 32 ± 10 years (range, 13 – 52 years). Two skeletally mature patients (one 13-year-old girl and one 16-year-old boy) were less than 18 years of age. The right ankle was affected in 29 patients and the left in 21. Thirty-six patients described a specific injury, including one or multiple ankle sprains (24 patients), a fall from a height, or other injuries (mostly sports related). The median time interval between the start of symptoms and surgery was 17 months (range, 1 month – 31 years). The mean BMI at the time of follow-up was 26.4 ± 4.2 kg/m^2. The mean duration of follow-up was 141 ± 34 months (range, 101 – 242 months).

Clinical outcome

The Ogilvie-Harris score was excellent in 20%, good in 58%, fair in 22%, and poor in 0% (Table 2). According to the Berndt and Harty outcome question, 74% of the patients rated their ankles as good, 20% as fair and 6% as poor. The median AOFAS score was 88 (range, 64 – 100). SF-36 subscale scores ranged from a mean of 71 ± 16 for the vitality component to 94 ± 22 for the role emotional component (Figure 3). The scores for the general health perceptions and role emotional subscales were significantly higher in the study group compared with the Dutch population normative data (p = 0.048 and 0.014, respectively).

Forty-six (94%) of the 49 patients who had worked before the onset of ankle symptoms had resumed work. The age of the patients who had resumed work (mean age at surgery, 31 years) did not differ significantly from the age of the patients who had not resumed work (mean, 23 years; p = 0.35). Thirty-seven (88%) of the 42 patients who had played sports had resumed playing sports. Two of these patients indicated that they had changed the type of sport. The sports played primarily were soccer, tennis, jogging, bicycle racing, fitness training, and field hockey. The age of the patients who had resumed playing sports (mean, 31 years) did not differ significantly from the age of patients who had not resumed playing sports (mean, 29 years; p = 0.77).

Baseline radiographic data

The mean preoperative size of the defects was 11.4 ± 4.2 in the anteroposterior direction, 7.8 ± 2.8 mm in the mediolateral direction, and 7.1 ± 3.3 mm in the craniocaudal direction. One-half of the OCDs were located on the centromedial aspect of the talar dome (see Table 1). Seven OCDs were classified as Berndt and Harty stage I, one as stage II, six as stage III, two as stage IV, and 29 as stage V. Five defects could not be classified according to the Berndt and Harty system because either the OCD was not visible on preoperative radiographs or preoperative radiographs were unavailable.

Radiographic outcome

Examination of the radiographs of the 48 patients who attended the follow-up visit revealed an OCD on 42 of the anteroposterior mortise views, 39 of the heel-rise mortise views, and two of the lateral views (Figure 4). The OA classification at the time of follow-up was grade 0 on 16 radiographs (33%), grade I on 30 (63%), grade II on two (4%), and grade III on zero. Thirty-two (67%) patients showed no progression and 16 (33%) showed progression by one grade (see

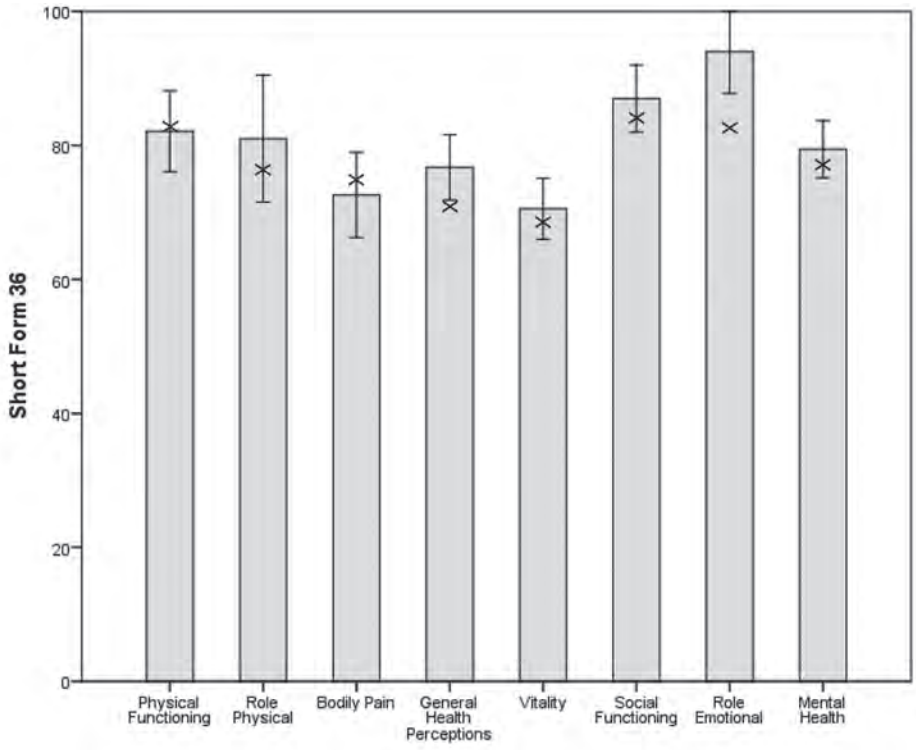


Figure 3. Short Form-36 subscale scores of the study group (gray bar = mean and error bar = 95% confidence interval) compared with the general population norms (× = mean).

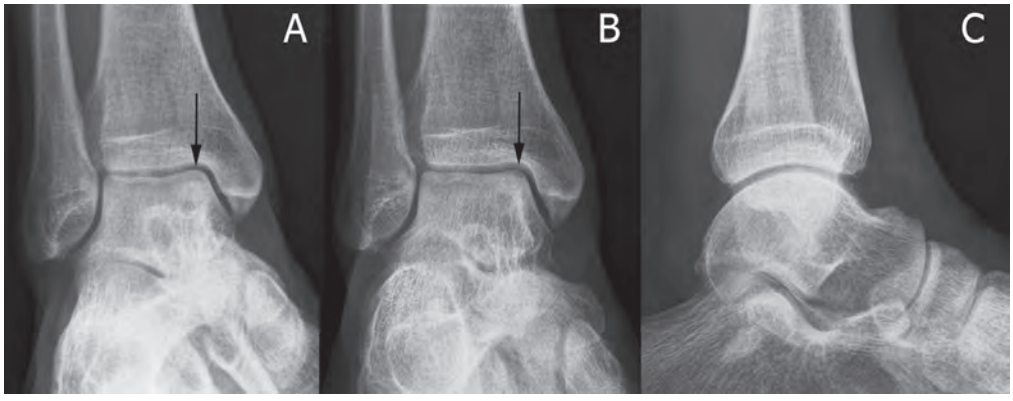


Figure 4. Radiographs of an ankle with a centromedial talar osteochondral defect at the time of follow-up. A subtle remnant of the defect (arrow) is visible on the anteroposterior mortise (A) and heel-rise (B) views; the defect cannot be detected on the lateral view (C).

Table 1. Patient characteristics and primary outcomes

Sex	Age at surgery (yr)	Side	Trauma	Duration of symptoms (mo)	Location*	Surgical procedure†	Duration of follow-up (mo)	Ogilvie-Harris score	Osteoarthritis classification	
									Preop.	Final
M	31	R	Y	36	AL	ADD	127	Excellent	0	0
F	32	R	Y	18	PC	AD	144	Excellent	0	0
F	24	R	N	6	CM	ADD	141	Good	0	1
F	24	R	Y	1	CM	AD	138	Good	0	0
M	26	R	Y	10	PM	ADD	124	Good	0	0
M	46	R	Y	32	PL	AD	112	Fair	0	1
M	36	R	N	42	CC	ADD	128	Good	1	1
M	47	R	N	48	CL	ADD	101	Good	1	1
M	20	L	Y	24	CL	AD	112	Good	0	1
M	16	L	N	24	CM	ADD	148	Fair	0	0
M	33	L	Y	48	CM	ADD	104	Fair	1	1
M	20	L	Y	24	CM	ADD	167	Good	1	1
F	28	L	N	36	CM	ADD	155	Fair	0	1
M	33	L	Y	24	AL	AD	198	Good	0	1
M	37	R	Y	24	CL	ADD	120	Excellent	0	1
F	20	R	Y	84	CM	ADD	148	Good	1‡	1
M	29	R	Y	36	CM	ADD	131	Good	1	1
F	22	L	N	60	PM	ADD	113	Good	0	0
M	48	R	N	144	CM	ADD	111	Good	2	2
M	38	R	Y	12	CL	ADD	106	Fair	1	1
F	45	L	Y	372	AL	AD	110	Excellent	0	0
M	34	L	N	12	CM	ADD	186	Good	1	1
F	51	R	N	60	CM	ADD	221	Good	2‡	2
M	19	L	Y	12	CM	AD	112	Excellent	0	1
F	52	L	N	12	CM	AD	134	Fair	0	1
F	36	R	Y	26	CM	ADD	120	Fair	1	1
F	39	R	Y	4	CL	ADD	134	Excellent	0	1
M	35	R	N	12	CM	ADD	106	Good	0	1
F	36	R	Y	9	PM	AD	115	Good	0	0
M	34	L	Y	3	CM	ADD	158	Excellent	1	1
F	21	R	Y	56	CM	PDD	114	Fair	0	0
M	29	R	Y	60	CL	PDD	106	Fair	0	1
M	27	L	Y	9	CL	ADD	124	Good	1	1
F	24	R	Y	6	CM	ADD	189	Good	0	1
F	38	L	N	9	CC	ADD	121	Excellent	0	0
M	48	R	Y	15	CM	ADD	163	Good	0	0
F	21	R	Y	24	PM	ADD	158	Good	0	0
M	42	L	Y	24	CM	PD	113	Good	1	1
F	13	R	Y	13	PL	ADD	174	Good	1	1
M	35	R	Y	12	CM	AD	142	Good	0	0

Table 1. Patient characteristics and primary outcomes

Sex	Age at surgery (yr)	Side	Trauma	Duration of symptoms (mo)	Location*	Surgical procedure†	Duration of follow-up (mo)	Ogilvie-Harris score	Osteoarthritis classification	
									Preop.	Final
M	26	R	Y	11	PL	ADD	139	Good	0	1
F	23	R	Y	48	CM	ADD	152	Good	0	0
M	27	L	Y	12	CM	ADD	112	Fair	0	1
F	20	R	N	14	CM	ADD	242	Excellent	§	§
M	30	L	N	45	AL	ADD	137	Good	§	§
M	33	R	Y	9	CL	ADD	115	Good	1	1
F	27	L	Y	8	PM	ADD	218	Good	0	1
M	26	L	Y	12	AL	ADD	205	Fair	0	0
M	45	L	Y	12	CM	ADD	141	Good	0	0

* AL = anterolateral, CC = centrocentral, CL = centrolateral, CM = centromedial, PC = posterocentral, PL = posterolateral, and PM = posteromedial. † AD = anterior debridement, ADD = anterior debridement and drilling, PD = posterior debridement, and PDD = posterior debridement and drilling. ‡ The classification of the first postoperative radiographs is given because preoperative radiographs were unavailable. § The patients did not attend the follow-up visit, so final radiographs were not obtained, but the patients completed the questionnaires by mail.

Table 2. Ogilvie-Harris score[304] at the time of final follow-up

Component	No. of patients			
	Poor	Fair	Good	Excellent
Pain	0	8	23	19
Swelling	0	2	12	36
Stiffness	0	6	20	24
Limp	0	0	2	48
Activity	0	9	12	29
Final score*	0	11	29	10

* For each patient, the lowest item determines the final score.

Table 1). Progression of OA had occurred in 47% of the noncystic defects (Berndt and Harty stages I to IV) compared with 32% of the cystic defects (stage V); this difference was not significant (p = 0.35). The five defects that could not be classified according to Berndt and Harty staging system showed no progression of OA.

Prognostic factors

None of the investigated prognostic factors was found to be significantly associated with the Ogilvie-Harris score or progression of OA. For example, the Ogilvie-Harris score was good or excellent for 78% of the lateral defects, 100% of the central defects, and 76% of the medial defects (p = 0.63). Likewise, dichotomous analysis of the continuous factors did not reveal any significance associations. For example, the Ogilvie-Harris score was good or excellent for 70% of the OCDs that were ≤11 mm in size compared with 82% of the OCDs that were >11 mm in size (OR, 2.0; 95% CI, 0.42 – 9.6; p = 0.39).

Table 3. Results of published studies with a mean follow-up of 5 years or more

Authors	Year	N	Follow-up* (yr)	Outcome measures	Good or excellent score
Baker and Morales	1999	12	10 (8 - 14)	Own scoring system	83%
Schuman et al.	2002	22	5 (2 - 11)	Ogilvie-Harris score	86%
Hunt and Sherman†	2003	28	6 (1 - 14)	Berndt & Harty score	46%
Ferkel et al.	2008	50	6 (2 - 13)	Alexander scale	72%
Becher et al.	2010	39	6 (1 - 10)	Hannover scoring system	79%
Choi et al.	2012	173	6 (2 - 10)	AOFAS‡	77%
Present study	2013	50	12 (8 - 20)	Ogilvie-Harris score	78%

* The values are given as the mean, with the range in parentheses. † Eight patients in this study had had previous ankle surgery. ‡ AOFAS = American Orthopaedic Foot & Ankle Society ankle-hindfoot score.

Prospective cohort

Fourteen patients evaluated in the current study had been evaluated 9 years previously in another study.[346] A comparison of the Ogilvie-Harris scores in the present study with those in the previous study revealed that the scores of nine patients had remained unchanged, three had worsened, and two had improved ($p = 0.66$).

Complications and reoperations

Four patients had complications, consisting of an area of hypoesthesia of the skin innervated by the superficial peroneal nerve in three patients and hypoesthesia of the first dorsal webspace in one. The complications were not reported by the patients but found on the physical examination.

Five patients required a total of six repeat surgical procedures because of persistent or recurrent symptoms, including symptoms due to new trauma. Repeat debridement and bone marrow stimulation was performed arthroscopically in four patients and in an open fashion in one; the latter patient underwent additional arthroscopic debridement 18 months later. In addition, two of these patients received intra-articular hyaluronic acid injections. The median time from the initial surgery to the repeat surgery was 21 months (range, 6 – 111 months). Three of these patients had a good Ogilvie-Harris score and two had a fair score at the time of final follow-up. The median AOFAS was 80 (range, 75 – 88).

Discussion

To our knowledge, the present study represents the longest reported follow-up of arthroscopic treatment for OCDs of the talus to date. The subjective outcome was good or excellent in 74% to 78% of the patients, depending on the outcome instrument used. Quality of life was at least comparable with that of the general population; six subscales of the SF-36 were comparable with population norms and two were superior. Most of the study group had resumed work and sports. Two-thirds of the patients had no radiographic progression of OA and one-third showed progression by one grade; none of the radiographs showed progression by two or three grades.

The clinical findings concurred with those of previous studies with a mean follow-up of more than 5 years (Table 3),[30,44,77,128,190,346] although there were some differences involving the treatment and outcome measures used. The results of the present study suggest that the intermediate-term results of arthroscopic treatment reported in previous studies are maintained over time.

The radiographic results were comparable with those reported by Ferkel et al. at a

mean follow-up of 6 years.[128] In that study, 66% of the patients showed no change in arthritis grade, 30% had a progression of one grade, 2% had a progression of two grades, and 2% had a progression of three grades.

In the present study, osteophytes were observed on the radiographs of 32 of 48 patients at the time of follow-up. It is unknown whether this prevalence can be attributed to the presence of the OCD, to preexisting OA changes, to the active nature of the patient group, or to the treatment. The relatively high percentage of patients with stage-I OA (63%; 30 patients) at the time of follow-up may be partially explained by the fact that 14 patients in the study group were at stage I preoperatively (see Table 1). It is known that osteophytes frequently recur, often asymptomatic, after treatment.[394]

We had hypothesized that the size of the OCD would be a significant predictor of outcome, as has been reported in some of the previous studies that investigated predictors of outcome of arthroscopic treatment of OCDs (Table 4).[44,76,77,82,128,156,165,190,235,244,334] However, none of the predictive factors investigated in the present study was found to be significantly associated with the clinical or radiographic outcome. The fact that no prognostic factors were identified may have been due to insufficient study power. In comparison, Chuckpaiwong et al. and Choi et al. assessed outcome predictors in cohorts that included more than 100 patients.[76,77,82]

The long-term results of arthroscopic treatment of OCDs may be superior to those of open treatment. Canale and Belding studied 15 defects treated with open excision and curettage.[69] After a mean follow-up of 11 years (range, 2 – 26 years), 11 (73%) of the patients had good clinical results and approximately 50% had had degeneration of the joint. In 1989, Angermann and Jensen reported on 18 patients who had undergone open excision and drilling.[22] After a mean follow-up of 12 years (range, 9 – 15 years), almost all patients had persistent symptoms and 17% had OA. Although the results of the present study compare favorably with those of the previous studies, a direct comparison may not be reliable because patient characteristics could have differed among the studies.

Bone marrow stimulation can be accomplished by several different surgical methods.[458] The objective is to remove all unstable cartilage and the underlying necrotic bone and then to stimulate healing of the defect. Opening the subchondral bone can be accomplished with use of a curette, shaver, small drill, Kirschner wire, or microfracture awl. Drilling was used in the 1990s, but microfracture has gained popularity since 2000.[368] Drilling might cause necrosis because of heating, but the drill or Kirschner wire is cooled by the arthroscopic fluid environment. The use of a microfracture awl is based on the theory that this results in microfractures of the trabeculae rather than destruction of the bone, thereby inducing a healing response.[368] A further advantage is that defects can be treated "around the corner" because the end of the awl is curved. However, the microfracture technique may create loose bony particles that become easily detached on withdrawal of the awl.[409] An experimental study that compared microfracture and drilling in rabbit knees indicated that microfracture produces fractured and compacted bone around the holes, essentially sealing the holes off from viable bone marrow, whereas drilling removes bone from the holes to provide access channels to marrow stroma.[73] However, since these differences have not been shown to affect the clinical outcome, the results of the present study – evaluating bone marrow stimulation performed before the era of microfracture – may be comparable with those of the contemporary microfracture technique.

The present study has limitations. First, its retrospective nature does not allow objective comparison with the preoperative clinical

Table 4. Prognostic factors of success after arthroscopic treatment of osteochondral talar defects according to the literature

Study	N	Mean follow-up (mo)	Outcome	Prognostic factors										
				Defect size	Defect location	Stage	Preop. OA	Age	BMI	Sex	Affected side	Trauma	Duration of symptoms	Duration of follow-up
Kumai et al., 1999	18	114	Berndt and Harty outcome question					yes (<30 yr)						
Hunt and Sherman, 2003	28	66	Berndt and Harty outcome question, Martin score, SANE			Arthroscopic: NS		NS						NS
Robinson et al., 2003	65	42	Berndt and Harty outcome question		NS	MRI: yes (Hepple grade 5 vs. 1-4)		NS				NS	Yes (<1 yr)	
Gobbi et al., 2006	33	53	AOFAS	Yes (cont.)										
Chuckpaiwong et al., 2008	105	32	VAS, AOFAS, Roles and Maudsley score	Yes (<15 mm)				Yes (cont.)	Yes (cont.)	NS		Yes	Yes (cont.)	
Ferkel et al., 2008	50	71	AOFAS, Weber score		NS	Arthroscopic: yes (Ferkel grade A-C vs. D-F); radiographic, CT, and MRI: NS		NS		NS	NS		NS	NS
Choi et al., 2009	120	45	AOFAS	Yes (<15 mm2)	NS			NS				NS	NS	
Lee et al., 2010	35	33	AOFAS	NS				NS	NS					Yes (<1 yr)
Guo et al., 2010	43	24	Patient grading	Yes (<10 mm)	NS			NS		NS				
Becher et al., 2010	39	70	HSS, VAS					NS	Yes (<25 kg/m2)					
Choi et al., 2012	173	70	AOFAS	Yes (<15 mm2)	NS			NS		NS		NS	NS	
Present study	50	141	Ogilvie-Harris score, OA-classification	NS	NS	Radiographic: NS	NS	NS	NS	NS	NS	NS	NS	NS

AOFAS = American Orthopaedic Foot & Ankle Society ankle-hindfoot score, BMI = body mass index, cont. = continuous (i.e., no cutoff point defined), CT = computed tomography, HSS = Hannover scoring system, MRI = magnetic resonance imaging, NS = not significant, OA = osteoarthritis, SANE = Single Assessment Numeric Evaluation, and VAS, visual analogue scale.

situation. Although a cohort of patients was analyzed prospectively and compared with those of a previous study,[346] only some of the patients in the previous series met the inclusion criteria of the present study. Second, the bone marrow stimulation was performed with use of more than one operative technique. However, in each case, bone marrow stimulation was ensured by sufficient penetration of the sclerotic base of the OCD followed by observation of bleeding of the base. Third, five patients underwent a reoperation after the initial arthroscopy. These patients were analyzed according to their final outcome rather than being reported as failures, reflecting the focus on subjective patient outcomes. This allowed comparison with other studies in which success rates were also reported according to the final outcome rather than the reoperation rate.[128,190,346] The AOFAS score of the patients who underwent a reoperation (median, 80) was similar to the score following repeat procedures reported by Savva et al. (mean, 81).[341] Finally, univariate analysis was used to assess outcome predictors, as multivariate regression analysis could not be performed because of sample size restrictions.

In conclusion, the results of the present study suggest that the initial success rates of arthroscopic debridement and bone marrow stimulation for the treatment of OCDs of the talus are maintained over time, and no factors that were predictive of the outcome could be identified.

Chapter 7

Potential pitfall in the microfracturing technique during the arthroscopic treatment of an osteochondral lesion

Christiaan J.A. van Bergen
Peter A.J. de Leeuw
C. Niek van Dijk

Knee Surgery, Sports Traumatology, Arthroscopy
2009;17(2):184-187.

Abstract

Debridement and bone marrow stimulation of the subchondral bone is currently considered to be the primary surgical treatment of most osteochondral lesions of the talus. Different methods of bone marrow stimulation are used, including drilling, abrasion, and microfracturing. The latter has gained recent popularity. This technical describes a potential pitfall in the microfracturing technique. The microfracture awl can easily create small bony particles on retrieval of the probe that may stay behind in the joint. It is emphasized that the joint should be carefully inspected and flushed at the end of each procedure, in order to prevent leaving behind any loose bony particles.

Introduction

Osteochondral defects (OCD) of the talus are often preceded by a trauma.[422] The lesions typically cause deep ankle pain on weight bearing, and may have a major impact on the patient's daily life and (sporting) activities. The diagnosis is frequently delayed, since the complaints may be attributed to the previous trauma.[422] Both conventional radiographs and additional diagnostics, such as computed tomography (CT) or magnetic resonance imaging, may reveal the lesion.[432]

Various treatment options exist, including nonoperative treatment, debridement with or without bone marrow stimulation, autologous chondrocyte implantation, allograft transplantation, and osteochondral autograft

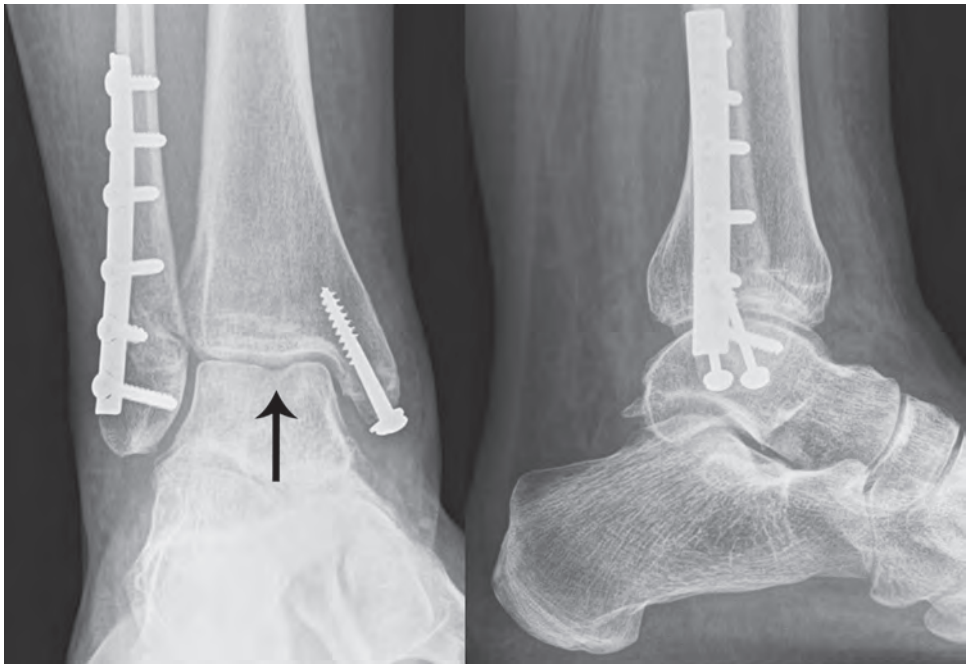


Figure 1. Preoperative anteroposterior (left) and lateral (right) weight-bearing radiographs of the right ankle of a 30-year-old female with persistent deep ankle pain after a successfully treated bimalleolar ankle fracture. The X-rays reveal an osteochondral lesion located in the central talar dome (arrow). The osteosynthesis material is also seen.

transplantation or mosaicplasty.[432,457] Despite advancements in some of these options, arthroscopic debridement combined with bone marrow stimulation is still the best currently available treatment.[439] It is considered the treatment of choice for primary lesions not exceeding 15 mm in diameter.[82,147]

Different methods are used to approach the lesion during arthroscopy, e.g., full plantar flexion, distraction, and transmalleolar or retrograde drilling.[125,334,346,381] Depending on the location of the defect, the arthroscopic approach can be performed from either anterior or posterior.[432] Furthermore, different tools for bone marrow stimulation can be used, i.e., a K-wire, drill or microfracture awl. Bone marrow stimulation by means of the microfracture technique has recently gained popularity.[368] One of the advantages of this approach in the ankle joint is its accessibility due to the curved end of the awl. In this report we describe a potentially important pitfall that is related to this procedure.

Case report

A 30-year-old female presented to our clinic with an OCD in the central talar dome of the right ankle. The medical history revealed a bimalleolar ankle fracture, which had been surgically treated 1 year earlier. At the time of her visit, the fracture had healed, but the patient had developed deep ankle pain on weight bearing. On examination, there was no swelling. The range of motion was slightly diminished, with a dorsiflexion-plantar flexion of 10-0-40°, compared to 15-0-45° on the healthy side. On palpation, there was no recognizable tenderness.

Anteroposterior and lateral weight-bearing radiographs revealed an OCD located in the central talar dome (Figure 1). A CT scan of the ankle confirmed this finding, and showed the exact location and extent of the lesion. Treatment by means of arthroscopic debridement and microfracturing through an anterior approach was scheduled.

Surgical technique

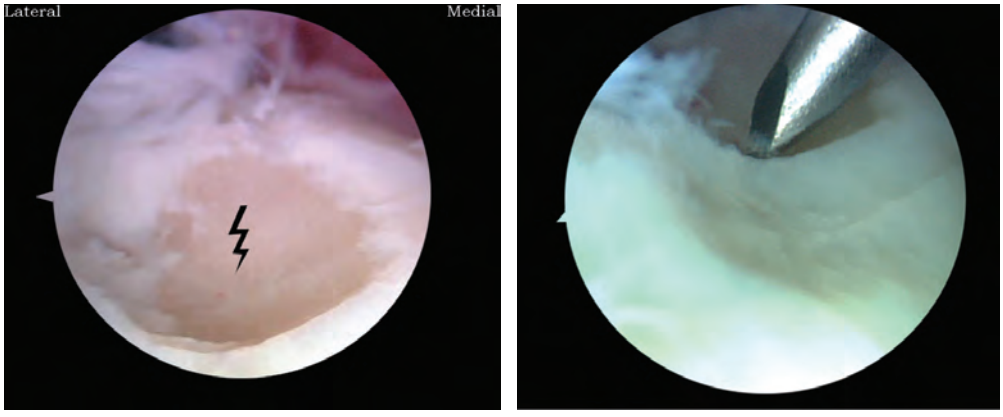
During the procedure, the patient was placed in a supine position, with slight elevation of the ipsilateral buttock and the hip supported. A tourniquet was applied around the involved upper leg and was inflated up to 300 mmHg. For irrigation, normal saline was used with gravity flow. The procedure was performed under spinal anesthesia. The anterior ankle arthroscopic approach was performed by means of routine anteromedial and anterolateral portal placement.[432]

With the arthroscope in the anterolateral portal, the ankle was fully plantarflexed until the OCD came into view (Figure 2A). The contours of the defect were defined with a probe, and the edges were sharpened with a curette. Then a shaver system (Bone Cutter Dyonics, Smith & Nephew, Andover, Massachusetts) was used to debride the OCD and underlying necrotic talar bone.

Next, a microfracture awl, angled 45°, was introduced through the anteromedial portal and the subchondral plate was punctured several times at intervals of approximately 3 mm (Figure 2B).[368] On inspection, it was noted that multiple loose bony fragments were created during retrieval of the awl (Figure 3A). The fragments were carefully identified, and were removed with a grasper (Figure 3B). At the end of the procedure, the joint was extensively flushed to wash out all possible remaining bony particles. After removal of the instruments the incisions were sutured with 3.0 Ethilon sutures.

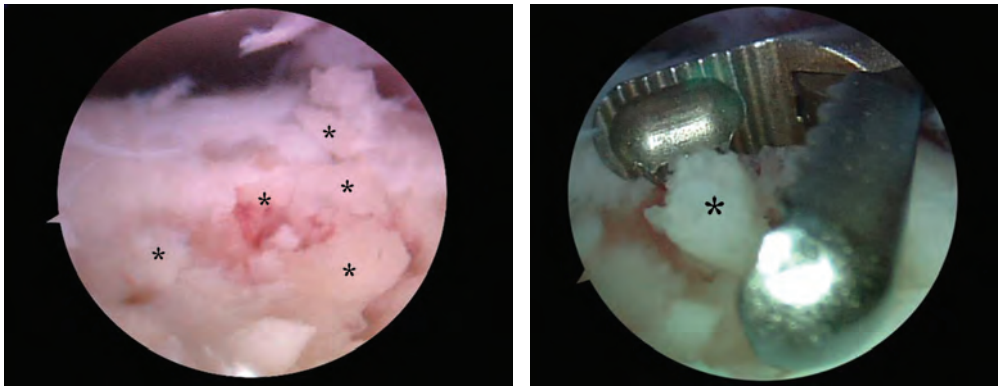
Postoperative course

Postoperatively, the patient was prescribed partial weight bearing for 6 weeks. She had an uneventful recovery.



A B

Figure 2. Intraoperative view of the untreated lesion (ϟ) of the same patient as in figure 1. The arthroscope is located in the anterolateral portal (A). After debridement of the defect, the subchondral bone is pierced with the microfracture awl (B).



A B

Figure 3. Arthroscopic view of the same lesion as in figures 1 and 2, after microfracturing. Multiple loose fragments (*) are seen (A). All fragments are removed with a grasper (B), the lesion is again debrided, and the ankle joint is flushed.

Discussion

Arthroscopic debridement and bone marrow stimulation is the primary treatment for most osteochondral lesions of the talus, with 87% good or excellent results.[439] The objective of the technique is firstly to remove all unstable cartilage, including the underlying necrotic bone, and secondly to stimulate healing of the defect by opening the subchondral bone. The latter is achieved by creating several defects into the calcified zone that usually covers the defect. Irrespective of the technique used, the aim of the procedure is to stimulate the formation of a fibrin clot into the defect. Pluripotential stem cells are recruited from the bone marrow, and the formation of fibrocartilaginous tissue is initiated.[368] This can be accomplished by using a 2-mm drill, a 1.4-mm to 2-mm K-wire, or a microfracture awl.

The different instruments that can be used to open the subchondral bone each have specific advantages and disadvantages. Small diameter drills and K-wires have been successfully used in routine ankle arthroscopy.[346,424] Eventual necrosis, due to heat caused by the drilling, can be minimized by using low speed and sufficient flushing, which also improves visualization. Compared to a drill, the K-wire has the advantage of flexibility and thus less risk of breakage. The use of either a drill or a K-wire also allows a transmalleolar or retrograde approach to the lesion.[334,381] A drawback of the transmalleolar approach is the iatrogenic damage of the opposing tibial articular cartilage. Moreover, it has been associated with persistent pain and oedema, and even a stress fracture may occur.[334]

The bone marrow stimulation technique with a microfracture awl is based on the theory that the use of an awl results in microfractures of the trabeculae rather than destruction of the bone, thereby inducing a healing response.[368] An advantage is that lesions can be treated "around the corner", because the end of the awl is curved.[457] This makes constant distraction unnecessary, which may lead to fewer complications.[432] Furthermore, possible heat necrosis in the case of drilling without cooling is avoided.

We describe an important drawback of the procedure. With the microfracture technique, loose bony particles are created, which easily become detached upon withdrawal of the awl. If the particles are not removed properly, they may act as loose bodies. These might subsequently give rise to locking and cartilage damage (Figure 4).

Until better alternatives have been sufficiently investigated, debridement and bone marrow stimulation remains the treatment of choice for primary OCDs of the talus. The technique is reliable and reproducible, and is associated with a high percentage of good or excellent outcome.[439] However, when using the microfracture awl, one must be alert for the creation of intra-articular loose bodies, especially when the microfracturing awl is retrieved. The joint should be inspected carefully, any loose bodies should be removed, and we recommend extensive lavage at the end of each procedure.

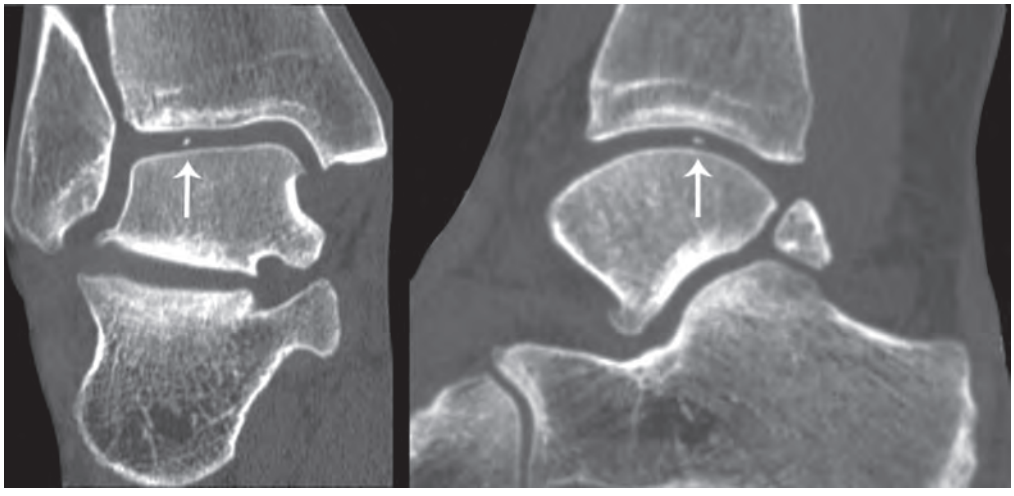


Figure 4. CT scan of a right ankle that shows a loose body, which is situated in the talar cartilage (arrow). Coronal (left) and sagittal (right) reconstructions are shown.

Chapter 8

Pulsed electromagnetic fields after arthroscopic treatment for osteochondral defects of the talus: double-blind randomized controlled multicenter trial

Christiaan J.A. van Bergen
Leendert Blankevoort
Rob J. de Haan
Inger N. Sierevelt
Duncan E. Meuffels
Pieter R.N. d'Hooghe
Rover Krips
Geert van Damme
C. Niek van Dijk

BioMed Central Musculoskeletal Disorders
2009;10(1):83.

Abstract

Background

Osteochondral talar defects usually affect athletic patients. The primary surgical treatment consists of arthroscopic debridement and microfracturing. Although this is mostly successful, early sport resumption is difficult to achieve, and it can take up to one year to obtain clinical improvement. Pulsed electromagnetic fields (PEMFs) may be effective for talar defects after arthroscopic treatment by promoting tissue healing, suppressing inflammation, and relieving pain. We hypothesize that PEMF-treatment compared to sham-treatment after arthroscopy will lead to earlier resumption of sports, and aim at 25% increase in patients that resume sports.

Methods/Design

A prospective, double-blind, randomized, placebo-controlled trial (RCT) will be conducted in five centers throughout the Netherlands and Belgium. Sixty-eight patients will be randomized to either active PEMF-treatment or sham-treatment for 60 days, 4 h daily. They will be followed-up for 1 year. The combined primary outcome measures are (a) the percentage of patients that resume and maintain sports, and (b) the time to resumption of sports, defined by the Ankle Activity Score. Secondary outcome measures include resumption of work, subjective and objective scoring systems (American Orthopaedic Foot and Ankle Society – ankle-hindfoot score, Foot Ankle Outcome Score, numeric rating scales of pain and satisfaction, EuroQol-5D), and computed tomography. Time to resumption of sports will be analyzed using Kaplan-Meier curves and log-rank tests.

Discussion

This trial will provide level-1 evidence on the effectiveness of PEMFs in the management of osteochondral ankle lesions after arthroscopy.

Trial registration

Netherlands Trial Register (NTR1636)

Background

Osteochondral defects (OCDs) of the talus often have a severe impact on the quality of life of the patients. The patients are usually young and athletic; most are male (62%) in the third decade of their lives after a traumatic ankle sprain.[457] The primary treatment of a symptomatic OCD consists of arthroscopic debridement and microfracturing.[432] This treatment yields 87% good or excellent results.[439] However, it can take up to 1 year to obtain improvement of clinical symptoms. Moreover, it is a great challenge to achieve early resumption of sports, which is the main goal of many of these young patients. In a series published in 2007, 26 "high-demand" athletic patients with an OCD returned to sports at a mean of 15 weeks after debridement and

microfracturing.[343] If we could shorten this period, we would considerably improve the quality of life in these active patients.

A potential solution to obtain this goal is the application of pulsed electromagnetic fields (PEMFs). Bassett in the 1960s and 1970s introduced and improved the clinical use of this treatment modality.[36,37] Since then, PEMFs have been applied increasingly, including their use in the treatment of osteoarthritis and (non-united) fractures.[188,353] They are designed as a portable PEMF generator, which consists of electromagnetic fields with an on-off effect of pulsing. This produces athermal effects that suppress inflammation, promote tissue healing, and relieve pain.[436] In vitro and in vivo studies have shown that PEMFs act as adenosine A2a agonists, leading to an increase of transforming growth factor β-1, thereby improving bone development, reducing cartilage damage and increasing chondrocyte proliferation.[6,47,58,83,84,98,99,133,163,316,384,438] These results clearly indicate improved regeneration of bone and possibly cartilage in a scientific setting.

Clinically, its favorable effects are less obvious. PEMF as a solitary treatment for osteoarthritis of the knee has been repeatedly investigated, with conflicting results.[131,188,278,385,400] Although the effect of PEMFs on osteoarthritis of the knee seems equivocal, their value in the additional treatment of other bony and cartilaginous pathologies is promising. PEMFs have been proven as a successful method in fracture healing, especially in the case of nonunion.[161,353,441] PEMF-treatment also favors the recovery of patients after arthroscopic treatment of chondral lesions in the knee, and reduces the use of nonsteroidal anti-inflammatory drugs.[462] To our knowledge, sport resumption with the use of PEMFs has not been investigated. Based on the above data, we believe that PEMFs may act on OCDs by improving bone regeneration and suppressing inflammation evoked by surgery.

When the above results are combined, it seems justified to state that additional PEMF-treatment may contribute to the management of OCDs. Our study question is: "Does treatment with PEMFs compared to sham device lead to earlier resumption of sports in a higher percentage of patients with an osteochondral defect of the talus after arthroscopic debridement and microfracturing?".

Methods/Design

Study design and informed consent

The study is designed as a double-blind, randomized, placebo controlled, multicenter trial, which is in accordance with the Declaration of Helsinki.[2] The methodology will follow CONSORT (Consolidation of Standards of Reporting Trials) guidelines.[57,289] Five centers in the Netherlands and Belgium will participate. Approval has been obtained from the local Medical Ethics Committees in the participating centers (MEC 08/236). Written informed consent for participation in the study will be obtained from all patients at study entry. An information letter notifying the patients' participation will be sent to their general practitioners.

Randomization

The participants will be randomized to receive either active PEMF-treatment or sham device, stratified for participating center, body mass index (≤ / >25 kg/m²),[42,82] and diameter of the defect on computed tomography (CT) (≤ / >10 mm).[457] Randomization will be performed in randomly allocated blocks of two or four patients using ALEA, a validated, web-based computer program.[3] The provider of the PEMF-devices (IGEAmedical, Carpi, Italy) will supply an equal number of active and sham devices identified

by code numbers, which correspond to the randomization program. Treatment allocation will be managed by an independent, unblinded research assistant (IS), who will not be involved in patient care or assessment. Patients and treating physicians as well as medical assessors will be blinded to the allocation of treatment. The code numbers will not be broken until all patients have completed the study.

Inclusion criteria

- Patients with a symptomatic OCD of the talus who are scheduled for arthroscopic debridement and microfracture[432]
- OCD diameter <15 mm on CT (in three dimensions: medial-lateral, anterior-posterior and superior-inferior)
- Ankle Activity Score (AAS) ≥4 before symptoms (Table 1)[170]
- Age 18 years or older

Exclusion criteria

- Concomitant OCD of the tibia
- Ankle osteoarthritis grade II or III[425]
- Ankle fracture <6 months before scheduled arthroscopy
- Surgical treatment of the index ankle performed <1 year before scheduled arthroscopy
- Concomitant painful or disabling disease of the lower limb
- Rheumatoid arthritis
- Pregnancy
- Implanted pacemaker
- Participation in concurrent trials
- Participation in previous trials <1 year, in which the subject has been exposed to radiation (radiographs or CT)
- Patients who are unable to fill out questionnaires and cannot have them filled out
- No informed consent

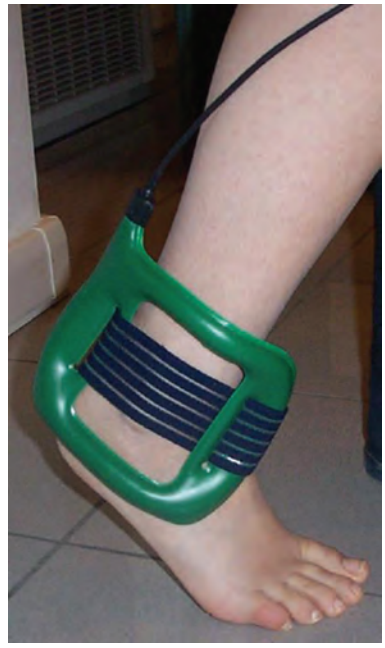


Figure 1. The application of pulsed electromagnetic fields on the ankle, generated in the green coil and attached with the elastic band (I-ONE, IGEAmedical, Carpi, Italy).

Device description

PEMFs are applied using a portable generator attached to the ankle (Figure 1). The coil in the active treatment device generates a peak magnetic field intensity of 1.5 mT, supplied by an electric pulse frequency of 75 Hz.[100] The sham devices do not differ from active devices in shape, color, weight, and in acoustic or visual signaling. Neither the active nor the sham device produces noise or sensation, and they are entirely indistinguishable. The only difference is the generated magnetic field; the sham device produces a negligible peak of less than 0.05 mT, supplied by the minimal current necessary to power the device indicators.

Table 1. Ankle Activity Score by Halasi et al.[170]

		Ankle Activity Score[a]		
Category	Sports and Activities	T	C	R
10	American football	10	9	8
	Basketball	10	9	8
	Gymnastics	10	9	8
	Handball	10	9	8
	Rugby	10	9	8
	Soccer	10	9	8
9	Hockey	9	8	7
	Korfball	9	8	7
	Martial arts: judo, karate, kung fu, taekwondo	9	8	7
	Orienteering	9	8	7
	Rhythmic gymnastics	9	8	7
	Volleyball	9	8	7
8	Boxing	8	7	6
	Freestyle snowboarding	8	7	6
	Ice hockey	8	7	6
	Tennis	8	7	6
	Wrestling	8	7	6
7	Aerobics, fitness	7	6	5
	Badminton	7	6	5
	Baseball	7	6	5
	Cross-country running (running on uneven ground)	7	6	5
	Modern pentathlon	7	6	5
	Squash	7	6	5
	Surfing, windsurfing	7	6	5
	Table tennis	7	6	5
	Track and field: field events	7	6	5
	Water skiing	7	6	5
6	Dancing	6	5	4
	Fencing	6	5	4
	Floorball	6	5	4
	Mountain and hill climbing	6	5	4
	Nordic skiing	6	5	4
	Parachuting	6	5	4
	Softball	6	5	4
	Special professions and working activitiesb	6		
5	Diving	5	5	4
	Scuba diving	5	5	4
	Skating, in-line skating	5	5	4
	Track and field: track events (running on even ground)	5	5	4
	Triathlon	5	5	4
	Weightlifting, body building	5	5	4
	All competitive sports of categories 4 and 3 with seasonal conditioning	5		
	Heavy physical work	5		

Table 1. Ankle Activity Score by Halasi et al.[170]

		Ankle Activity Score[a]		
Category	Sports and Activities	T	C	R
4	Alpine skiing and snowboarding	4	4	4
	Bowling/curling	4	4	4
	Golf	4	4	4
	Mountain biking/bmx	4	4	4
	Power lifting	4	4	4
	Sailing	4	4	4
	Physical work	4		
3	Cycling	3	3	3
	Equestrian	3	3	3
	Motorsports, technical sports	3	3	3
	Rowing, kayaking	3	3	3
	Shooting, archery	3	3	3
	Water polo and swimming	3	3	3
	Able to walk on any uneven ground	3		
2	No sports, everyday activities not limited	2		
1	Able to walk on even ground, but everyday activities limited	1		
0	Unable to walk, disabled because of ankle problems	0		

If multiple options are applicable, the highest level is chosen.
[a] C = lower competitive levels, R = recreational level (participation should be considered only if it exceeds 50 h per year), and T = top level (international elite, professional, national team, or first division).
[b] Special professions include ballet dancer, professional soldier, special rescue worker, stuntperson, and so forth.

Standard treatment and investigational treatment

All surgical procedures will be performed using a standardized technique.[432] Briefly, the ankle joint is approached by arthroscopy using an anterior or posterior approach. The OCD is identified with a probe and debrided with a curette and bonecutter shaver. All unstable bone and cartilage are removed. After full debridement, the subchondral bone is perforated with a microfracture awl, with intervals of approximately 3 mm. At the end of the procedure, a pressure bandage is applied.

After surgery, the protocol-based rehabilitation program, guided by a physiotherapist, will be equal in both groups. It will be initiated with partial (eggshell) weight bearing on crutches, as tolerated, and progressed to full weight bearing over a period of 6 weeks. During this period, active non–weight-bearing and partial weight-bearing sagittal range-of-motion exercises are encouraged, i.e., 15 min twice daily. After this 6-week period, resumption of sports will be permitted as tolerated, and will not be directed by the clinician.

In both groups the investigational treatment (active PEMF-treatment or sham device treatment) will start within 3 days after surgery. It will be applied 4 h daily (in one or two sessions) for a period of 60 days.[48,100] The patients' compliance will be monitored by a clock inside the device that records the hours of stimulation.

The prescription of nonsteroidal anti-inflammatory drugs will be avoided due to their negative effect on bone regeneration.[45] The use of paracetamol will be allowed

up to a maximum dose of 4 g/d and will be discontinued 1 week before the visits at baseline, 1 month, 2 months, 6 months, and 1 year.

Outcome measures

The combined primary outcome measures are: (a) the number of patients that resume and maintain sports during 12 months follow-up, and (b) the time to resumption of sports, defined by the AAS.

Secondary outcome measures are:

- Time to resumption of work
- American Orthopaedic Foot & Ankle Society (AOFAS) ankle-hindfoot score
- Foot and Ankle Outcome Score (FAOS)
- Quality of life (EuroQol-5D)
- Pain (numeric rating scale)
- Satisfaction (numeric rating scale)
- CT
- Adverse events

Definitions

Primary outcome measures

Because there is no consensus as to defining what actual resumption of sport is, as Saxena and Eakin stated,[343] we define time to resumption of sports as the time after arthroscopy (weeks) until initiation of any sport with a minimum level of the pre-symptoms level minus 1 point on the AAS, and maintained for at least 30 days. If a patient's activity level decreases to below the minimum level within 30 days after sport resumption, the resumption date will not be counted. To evaluate the level of sport activity, we will use the AAS that has been developed and validated by Halasi and associates.[170] This 10-point score is based on the type and level of sport or work, with 0 points indicating the lowest activity and 10 points indicating the highest activity (Table 1).

Secondary outcome measures

Resumption of work is defined as the ability to perform normal work exercises without any deficits in work quality.[358] The AOFAS score is a frequently used combined objective-subjective 100-point scale which devotes 40 points to pain, 50 points to function, and 10 points to alignment.[217] The subjective part was recently validated.[192] The FAOS is a subjective 42-item questionnaire assessing five subscales: pain, other symptoms, activities of daily living, sports, and quality of life. All items are scored on a Likert-scale, and each of the five subscales is transformed to a score of 0 (worst) to 100 (best). The original English version has been validated,[336] and the Dutch translation is currently being validated at our institution. The EuroQol (EQ-5D) is a validated and extensively used general health questionnaire to measure quality of life.[239] It comprises five dimensions: mobility, self-care, usual activities, pain/discomfort and anxiety/depression. Each dimension is marked as no problems, some problems, or severe problems, which results in a 1-digit number expressing the level selected for that dimension. The digits for five dimensions are combined in a 5-digit number describing the respondent's health state. The numeric rating scale (NRS) for pain consists of an 11-point scale (0 – 10) which represents the whole spectrum of no pain up to the worst pain imaginable.[139] Pain at rest and pain when running will be measured. Patients' satisfaction will be measured using a NRS where 0 indicates no satisfaction and 10 indicates maximally possible satisfaction.

To objectively assess bone repair, we will obtain multislice helical CT scans of the affected ankles at baseline and 1 year after surgery (Figure 2). CT scanning has been proven

to be accurate in the detection and follow-up of OCDs of the talus, regarding location and extent as well as healing of the defect.[440,460] The scanning protocol will involve "ultra high resolution" axial slices with an increment of 0.3 mm and a thickness of 0.6 mm, and multi-planar coronal and sagittal reconstructions of 1 mm.[408] The scans will be analyzed twice by a single physician, blinded to both treatment allocation and clinical outcome, measuring completeness, thickness, and level of the subchondral plate (i.e., flush, depressed, or proud).[154] Additionally, bone volume filling of the defect after 1 year will be measured, and graded as good (67% to 100%), moderate (34% to 66%), or poor (0% to 33%).[288]

Adverse events

Any (serious) adverse event during the trial period will be recorded. Adverse events are defined as any undesirable experience occurring to a subject during a clinical trial, whether or not considered related to the investigational treatment, e.g., infection, numbness, or paraesthesia. A serious adverse event (SAE) is any undesirable experience associated with the use of the investigational treatment that results in death, is life threatening (at the time of the event), requires hospitalization or prolongation of existing inpatients' hospitalization, or results in persistent or clinically relevant disability or incapacity. All SAEs will be reported to the central Medical Ethics Committee according to their requirements. Patients suffering from a SAE will stop their PEMF- or sham-treatment.

Data collection

For each randomized patient, a specially designed digital case report form (CRF) will be completed. The CRF consists of a sequential set of instructions with provision for data recording.

Internet-based remote data capture will be used for entering, managing, and validating data from the investigative sites. For this purpose, Oracle Clinical will be used, a program designed to meet industry regulations, including FDA 21CFR Part 11 Rule (March 20, 1997), ICH; Good Clinical Practice: Consolidated Guideline (May 9, 1997), and FDA Guidance for Industry "Computerized Systems Used In Clinical Trials" (May 10, 1999).

All randomized patients are identified by a patient identification number (PIN) in combination with a center number. Trial personnel will not pass names outside the local hospitals. The investigator will ensure that patients' anonymity is maintained. On CRFs or other documents submitted to the coordinating center, patients will not be identified by their names

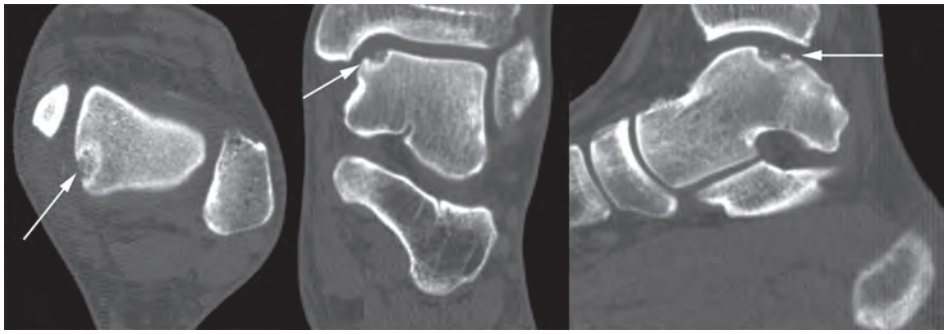


Figure 2. Preoperative computed tomography (axial, coronal, and sagittal slices) of the left ankle of a 25-year-old female showing a typical osteochondral defect located on the posteromedial talar dome (arrows).

but by a PIN in combination with a center number. The subject identification code list will be safeguarded by the investigator.

Data acquisition and follow-up

Participating patients will be assessed at the following time points (Table 2):

1. Preoperatively: information letter, informed consent, baseline characteristics (age, gender, weight, height, affected side, duration of symptoms, past medical history, smoking status), type of sport and profession, AAS (2×: before symptoms and at preoperative assessment), AOFAS score, FAOS, EQ-5D, NRS pain (2×: at rest and when running), CT: size, localization, and classification of the OCD (Table 3)[257]
2. 1-2 weeks postoperatively: check compliance, (S)AEs, wound inspection (healing, signs of infection)
3. 1 month postoperatively: check compliance, (S)AEs, resumption of work, EQ-5D, NRS pain (at rest) and satisfaction
4. 2 months postoperatively: check compliance, (S)AEs, resumption of sport and work, AAS, AOFAS score, FAOS, EQ-5D, NRS pain (at rest and when running, if applicable) and satisfaction, wound inspection, stop PEMF- or sham-treatment
5. 6 months postoperatively: resumption and maintenance of sport and work, AAS, EQ-5D, NRS pain (at rest and when running)
6. 1 year postoperatively: resumption and maintenance of sport and work, AAS, AOFAS score, FAOS, EQ-5D, NRS pain (at rest and

Table 2. Patient assessment

	Physician									Patient			
	Baseline characteristics*	Sport resumption	Work resumption	AAS	AOFAS score	CT	Wound inspection	Compliance	Adverse events	FAOS	EQ-5D	NRS pain	NRS satisfaction
Preoperative	X			X	X	X				X	X	X	
1 - 2 weeks							X	X	X				
1 month			X					X	X		X	X	X
2 months		X	X	X	X		X	X	X	X	X	X	X
6 months		X	X	X							X	X	
1 year		X	X	X	X	X			X	X	X	X	X

* Baseline characteristics include age, gender, weight, height, affected side, duration of symptoms, type of sport and profession, past medical history, smoking status, and size, localization and classification of osteochondral defect on computed tomography.
AAS = Ankle Activity Score, AOFAS score = American Orthopaedic Foot & Ankle Society ankle-hindfoot score, CT = computed tomography, EQ-5D = EuroQol questionnaire, FAOS = Foot and Ankle Outcome Score, and NRS = numeric rating scale.

Table 3. Computed tomography classification of osteochondral defects of the talus[257]

Grade	Description
I	Compression
II	Partially fractured but undisplaced
III	Completely fractured but undisplaced
IV	Displaced fracture
V	Radiolucent (fibrous) defect

when running) and satisfaction, (S)AEs, CT: subchondral plate and bone volume filling

Recording sport resumption

To assess the resumption of sports and work, the patients will keep a diary that will be supplied at inclusion. Every time they perform sports they will record the type of sport and activity level (i.e., professional, competitive, or recreational) in this diary. They will also record the resumption of work, as defined above. This diary will be used for the monitoring of resumption and maintenance of sports and activity levels. At the postoperative visits, the patients will be asked to check their diaries and report their sport activities and work resumption, to be filled out on the CRF. At 1 year, the diary will be collected for assessment and confirmation of resumption dates.

Sample size

Our sample size calculation is based on the combined primary endpoints (a) number of patients that resume and maintain sports during 12 months follow-up, and (b) the time to resumption of sport. Based on our experience, it is expected that 50% of patients will resume and maintain sports within 1 year after the surgical intervention. Offering additional PEMF-treatment, we aim to improve this outcome to 75%. Of the patients who resume to sport, the mean time to return to sports after debridement and microfracturing is 15 ± 4 weeks.[343] We consider a 20% reduction in time to return to sports as clinically relevant, i.e., 3 weeks. A sample size of 30 patients in each group (60 patients in total) will have 80% power to detect a joint difference (control group proportion of 0.50 versus treatment proportion of 0.75; control group mean of 15 weeks versus treatment group mean of 12, assuming a common standard deviation of 4), using a Fisher's combination test with a 0.05 two-sided significance level. In reported clinical trials with this device, 9% to 13% of included patients dropped out.[48,462] Therefore, 34 patients will be included in each treatment group (68 patients in total).

Statistical methods

The following baseline characteristics will be summarized using descriptive statistics: number of patients, gender, age, affected side, duration of symptoms (months), prior ankle surgery, body mass index (kg/m^2), trauma, smoking, size of lesion (mm), classification, duration of PEMF- or sham-treatment (hours), AAS, NRS pain, FAOS, AOFAS score, and EQ-5D. Continuous data will be presented as mean and standard deviation if normally distributed, or as median and range in case of skewed distribution.

The main analysis of this trial consists of a comparison between the treatment groups of the primary outcomes: number of patients who resume and maintain sports and the time to resumption of sport (of the patients who resume sport). The number of patients who resume sport will be analyzed using the two-group X^2 test, whereas the difference in mean weeks to sport resumption will be analyzed by a two-group Student's t-test. Both p-values will be combined using the Fisher's combination test. Kaplan-Meier survival curves and the log-rank test will also be used for comparing time to resumption of sport. The stratification variables will be included in the primary analysis.

The repeated datastructure of the secondary outcomes (AAS, AOFAS score, FAOS, EQ-5D, NRS pain, and NRS satisfaction) will be analyzed with linear mixed models, including a time-treatment interaction effect. The number of adverse events and time to resumption of work will be analyzed using a X^2 test or log-rank test, when appropriate. Analyses will be based on the

intention-to-treat principle and performed in SPSS. Statistical uncertainty will be quantified via 95% confidence intervals.

Participating centers and inclusion time

Centers that will participate and their estimated annual inclusions are:

1. Academic Medical Center, Amsterdam, the Netherlands (Prof. Dr. C.N. van Dijk and Dr. G.M.M.J. Kerkhoffs): 24 patients
2. Erasmus MC, University Medical Center Rotterdam, the Netherlands (Dr. D.E. Meuffels and Dr. R. Heijboer): 20 patients
3. Stedelijk Ziekenhuis Roeselare, Belgium (Dr. P.R.N. d'Hooghe): 8 patients
4. Diaconessenhuis, Leiden, the Netherlands (Dr. R. Krips): 8 patients
5. Algemeen Ziekenhuis Sint Lucas, Brugge, Belgium (Dr. G. van Damme): 8 patients

It will take an estimated year to include 68 patients. With 1 year follow-up, this trial will take an expected 2 years to be performed.

Quality assurance

A clinical research associate from our Clinical Research Unit will monitor the trial. All centers will be monitored twice: after the fourth included patient after 2 months of follow-up and after the last patient's last visit. Monitoring will consist of 100% check informed consent procedure, registration of adverse events, completeness of the trial master file, and verification of source data (primary outcome in 10% sample).

Public disclosure and publication policy

This trial has been registered in the Netherlands Trial Register (NTR1636). Publication will be in accordance with the basic principles of the International Committee of Medical Journal Editors on publication policy.[4] The writing committee will consist of the following people: C.J.A. van Bergen, L. Blankevoort, R.J. de Haan, and C.N. van Dijk. All principal investigators at the participating centers will have the opportunity to scientifically contribute to the manuscript, and, if so, will be listed as an author. If they do not wish to contribute to the manuscript, they will be acknowledged in the order of the number of participants randomized. Other individuals who make substantial contributions to the trial will be acknowledged at the discretion of the writing committee.

Discussion

This paper describes the rationale and study protocol for conducting a double-blind, randomized controlled trial on the effectiveness of PEMF in the rehabilitation of ankle arthroscopy for OCDs of the talus.

The primary outcome measure focuses on sport resumption. This is a difficult measure, as several authors wrote previously,[34,169,343] since a univocal definition does not exist. By clearly defining sport resumption, we aim at providing evidence of any relevant differences between active and passive PEMF-treatment. Moreover, if our definition shows to be useful in the present study, it can be used for the design of future trials.

Regarding the treatment of OCDs of the talus, we consider bone regeneration more important than cartilage regeneration. Cartilage is not innervated; the patient's pain probably arises from the bony lesion.[112] Additionally, a differentiation can be made between OCDs localized in the ankle joint and those localized in the knee joint. Most studies concerning OCDs of the knee focus on cartilage repair rather than bone repair.[220,256] This seems reasonable since

the knee joint is less congruent and the OCDs are usually localized in high–load-bearing areas. Moreover, the knee joint is more susceptible to osteoarthritis than the ankle joint.[85,234] The ankle joint, however, has different biomechanical properties. The joint is more congruent and talar articular cartilage is thinner than distal femoral cartilage.[102] The load-bearing contact surface of the ankle joint is somewhat larger,[236,286,314] and the OCD is often smaller. Hence, the remaining intact surface of the talar dome is usually sufficiently large to bear the loads; contact surface pressures do not significantly change with talar defects up to 15 mm in diameter.[80] Combining these properties, we believe treatment of OCDs in the ankle joint should primarily aim at repair of the subchondral bone, and secondarily at coverage by fibrocartilaginous tissue. In this respect, PEMF-treatment may be particularly suitable for OCDs of the talus since its bone-healing capacity has been proven.[68,161,353,441]

This trial will contribute to the knowledge of the effectiveness of PEMF, and may improve health care of patients with an OCD. Given the modality's relatively simple technology and ease of use, it has high potential to provide a safe and effective additional treatment option for OCDs of the talus.

Acknowledgments

The authors are grateful to Stryker, Waardenburg, the Netherlands, for providing financial support, and to IGEAmedical, Carpi, Italy, for providing the PEMF- and sham-devices.

Part III
Secondary surgical treatment with a metal resurfacing inlay implant

Chapter 9

Novel metallic implantation technique for osteochondral defects of the talus: a cadaver study

Christiaan J.A. van Bergen
Maartje Zengerink
Leendert Blankevoort
Maayke N. van Sterkenburg
Jakob van Oldenrijk
C. Niek van Dijk

Acta Orthopaedica
2010;81(4):495-502.

Abstract

Background and purpose

A metallic inlay implant (HemiCAP) with 15 offset sizes has been developed for the treatment of localized osteochondral defects of the medial talar dome. The aim of this study was to test the following hypotheses: (1) a matching offset size is available for each talus, (2) the prosthetic device can be reproducibly implanted slightly recessed in relation to the talar cartilage level, and (3) with this implantation level, excessive contact pressures on the opposite tibial cartilage are avoided.

Methods

The prosthetic device was implanted in 11 intact fresh-frozen human cadaver ankles, aiming its surface 0.5 mm below cartilage level. The implantation level was measured at four margins of each implant. Intra-articular contact pressures were measured before and after implantation, with compressive forces of 1,000 to 2,000 N and the ankle joint in plantigrade position, 10˚ of dorsiflexion, and 14˚ of plantar flexion.

Results

There was a matching offset size available for each specimen. The mean implantation level was 0.45 ± 0.18 mm below the cartilage surface. The defect area accounted for a median of 3% (range, 0.02% – 18%) of the total ankle contact pressure before implantation. This was reduced to 0.1% (range, 0.02% – 13%) after prosthetic implantation.

Interpretation

These results suggest that the implant can be applied clinically in a safe way, with appropriate offset sizes for various talar domes and without excessive pressure on the opposite cartilage.

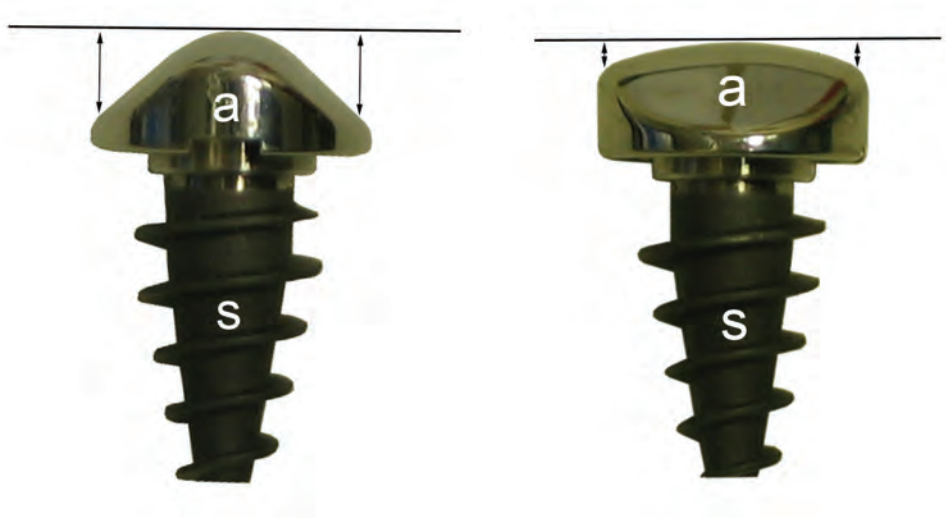
Introduction

Osteochondral talar defects (OCDs) have been reported in 7% to 41% of patients with lateral ankle ligament rupture.[251,376,422] Two-thirds of talar OCDs are located on the medial talar dome; these lesions are often deep and cup-shaped and are generally larger than lateral lesions.[322] OCDs may develop into subchondral cysts;[198,433] this is thought to occur due to intrusion of fluid through a bony defect, and hampers effective treatment.[328,334,349,433]

The primary treatment of most OCDs is arthroscopic debridement and microfracturing, with a success rate of 85%.[432,458] For failed primary treatment and large defects, there are various alternative treatment options, including cancellous bone grafting, osteochondral autograft transfer, and autologous chondrocyte implantation.[408,458]. However, each of these has disadvantages such as donor site morbidity, limited availability, and two-stage surgery.[312,408]

A novel metal inlay implantation technique (HemiCAP, Arthrosurface Inc., Franklin, MA, USA) was developed in 2007 for medial defects after failed primary treatment (Figure 1). Its clinical goals are to reduce pain and prevent (further) cyst formation by resurfacing the OCD. The talar implant set consists of 15 offset sizes to provide an implant that matches the geometry of the medial talar dome in a variety of talar specimens. A precise surgical technique is required in terms of implantation depth, position, and orientation because of the biomechanical properties of the ankle joint. A protruding implant may damage the opposite cartilage by causing excessive contact pressures during loading, which is thought to be due to "plowing" of the cartilage.[90,254,285] On the other hand, a deep implant might result in collapse of the adjacent cartilage due to insufficient support.[198]. Hence, an optimum middle course is aimed for. The talar dome cartilage thickness was found to be 1.42 ± 0.18 mm in an in vivo study.[444] Talar cartilage peak contact strain under weight-bearing conditions reached 35% ± 7%.[444]. We therefore propose an optimal implantation depth of 0.5 mm (35% of 1.4 mm) below the level of the articular cartilage surface.

The purpose of this study was to test the following hypotheses: (1) the set of 15 offset sizes is appropriate for a variety of talar dome curvatures; (2) the prosthetic device can be reproducibly implanted slightly recessed; and (3) excessive pressure on the opposite tibial cartilage can be prevented with 0.5 mm recessed implantation. To test these hypotheses, the prosthetic devices were implanted in cadaver ankle specimens, the implantation levels were measured, and the intra-articular contact pressures were measured before and after implantation.



A B

Figure 1. The metallic implant consists of a screw (s) and an articular component (a) with a diameter of 15 mm. There are 15 articular components with a variety of offset sizes (↕) with steps of 0.5 mm relative to the center. Anterior-posterior view (A). In this plane, offset sizes range from 3.5 to 5.5 mm. Medial-lateral view (B), with offset sizes ranging from 0.5 to 2.0 mm.

Material and methods

Specimens

Twelve fresh-frozen (–20°) cadaver ankles, amputated halfway along the tibia, were obtained from donors. During their lives, the donors had given informed consent for the use of their bodies for scientific or educational purposes. The specimens were thawed at room temperature. Normal ranges of motion and ligament stability were confirmed by physical examination. The talar dome was surgically exposed by a medial malleolar osteotomy. The modified Noyes and Stabler classification, as described by Recht et al., was used to grade macroscopically the talocrural joint cartilage surfaces.[300,326] Eleven specimens were graded 0 (intact cartilage). One specimen had a grade 3A lesion and was excluded from the study. The remaining 11 ankles (six left) originated from four males and six females (one bilateral) with a mean age of 79 years (range, 66 – 89 years).

Implant

The articular prosthetic device consists of a fixation screw and an articular component, which are connected via a taper lock (Figure 1). The cannulated fixation screw is made of titanium to allow osseointegration of the subchondral bone. The articular component is made of a cobalt chrome alloy with titanium spray undercoating, and has a diameter of 15 mm. There are 15 offset sizes, with increment sizes of 0.5 mm in the sagittal (0.5 – 2.0 mm) and coronal (3.5 – 5.5 mm) planes. The development of the offset sizes was based on geometric data reconstructed at our institution, using computed tomography scans of 52 patients with a talar OCD.

Surgical technique

CNvD and two assistants performed all surgical procedures according to a standardized technique. A longitudinal skin incision was made, and two screw holes were predrilled in the medial malleolus from distal to proximal. An anterior arthrotomy was performed, and the periosteum of the medial malleolus was incised. Two Hohmann retractors were placed to protect the anterior and posterior vital structures. Using an oscillating motorized saw and a chisel, the surgeon exposed the medial talar dome by creating a medial malleolar osteotomy. The osteotomy was aimed at the intersection between tibial plafond and medial malleolus, as described by Seil et al.[351] At this stage of the procedure, the preimplantation contact pressures were measured (see "Pressure measurements" below).

At the second stage of the operation, the prosthetic device was implanted. The lateral malleolus of the specimen was placed on a rolled-up apron in order to evert the talus for better exposure. A Kirschner wire was drilled through the distally retracted medial malleolus into the inferior talar body to maintain good exposure. A guide pin was drilled into the talus, perpendicular to the medial talar trochlea, using a special drill guide. This guide pin ensured good orientation of the cannulated instruments throughout the procedure. The position of the guide pin was initially checked with a contact probe, and it was repositioned in case of suboptimal position. After drilling and tapping of the pilot hole, the fixation screw was inserted into the subchondral bone up to a precise depth, indicated by a mark on the screwdriver at the level of the superficial cartilage. After flushing and cleaning, the implantation level of the screw was verified using a small trial button. If necessary, the screw level was adjusted carefully by turning it clockwise or anticlockwise.

The level of the adjacent cartilage relative to the screw (i.e., the radius of curvature) was measured anteriorly, posteriorly, medially, and laterally using a contact probe that was provided with the implantation set. Subsequently, a 15-mm circular incision of the cartilage was made using a circle-cutter, and a 15-mm implant bed was reamed. The articular component was considered appropriate when its offset sizes corresponded with the surface mapping measurements. An articular sizing trial cap was placed, aiming 0.5 mm below the level of the adjacent cartilage. If satisfied, the surgeon placed the final implant loosely on the screw to confirm correct rotation, and engaged it by means of a gentle hammer-stroke on an impactor. The ankle joint was flushed and cleaned to remove any remaining debris.

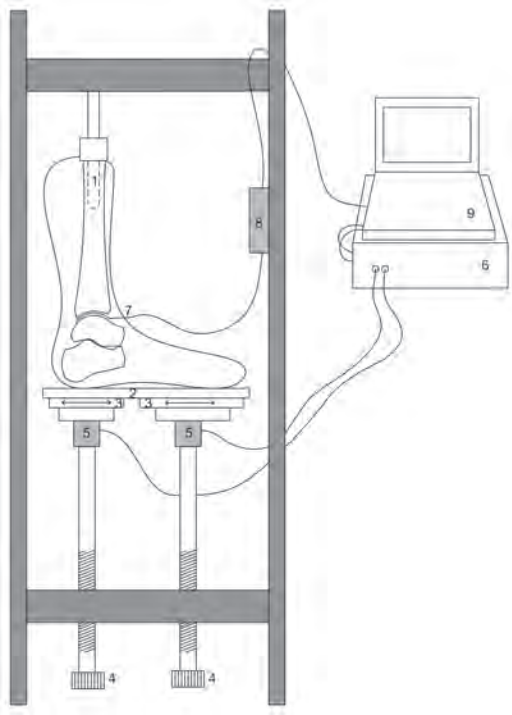
Implantation level

After the tali were excised and removed from the specimens, CJAvB measured the implantation level at the transition of the prosthetic implant and the adjacent cartilage surface at four locations (anterior, posterior, medial, and lateral) using a digital calliper in a blinded fashion; the readings were read and recorded by an assistant. The calliper (Absolute Digimatic Calliper 500-series, Mitutoyo Nederland BV, Veenendaal, the Netherlands) had a resolution of 0.01 mm and an accuracy of 0.02 mm (manufacturer's data). Each location was measured twice and averaged for analysis. Whether the central part of the implant protruded was assessed visually, specifically by a view tangential to the articular surface from both anteriorly and medially.

Testing material

Contact pressure was measured using a thin film pressure-sensitive system (Tekscan Inc., Boston, MA, USA), which is more accurate in measuring surface area, force, and pressure than the Fuji film pressure-sensitive technique.[28] The sensors are 0.1 mm thick and consist of electrical contacts in two perpendicular directions (rows and columns), separated by a semi-conductive layer. This layer provides an electrical resistance at each of the intersecting points. By measuring the changes in electrical current at each intersection point, the pressure distribution pattern can be measured and displayed on a screen. Sensor type 4000 was used, which has 572 sensing elements on a surface of 28 × 33 mm (62 sensing elements per cm^2), and a column and row width of 1.27 mm. The flexible pressure sensor was connected to a computer containing I-scan software (Figure 2).

A mechanical testing apparatus, developed by the Medical Technical Development Department of our institution, loaded the ankle during testing (Figure 2). On top it consisted of a shaft where a tibial nail was inserted; at the base it consisted of a base-plate with a rough surface on a ball bearing. The ball bearing allowed anteroposterior translation of the foot in neutral (plantigrade) position but not in the plantarflexed and dorsiflexed positions. To place and hold the ankle specimens in the desired flexion angle, custom-made wedge supports were attached to the base-plate (0° for plantigrade, 10° for dorsiflexion, and 14° for plantar flexion). These angles correspond to the mean sagittal ankle motion during the stance phase of gait in normal subjects.[367] The wedges were made of polyvinyl chloride and were covered with sand paper to prevent slipping of the specimens. The force was applied by gradually moving the base-plate upwards by turning two handle-actuated lead screws. The force transducers of the apparatus were attached to a data acquisition system that, after calibration, converted the output measured by the strain gages into force.



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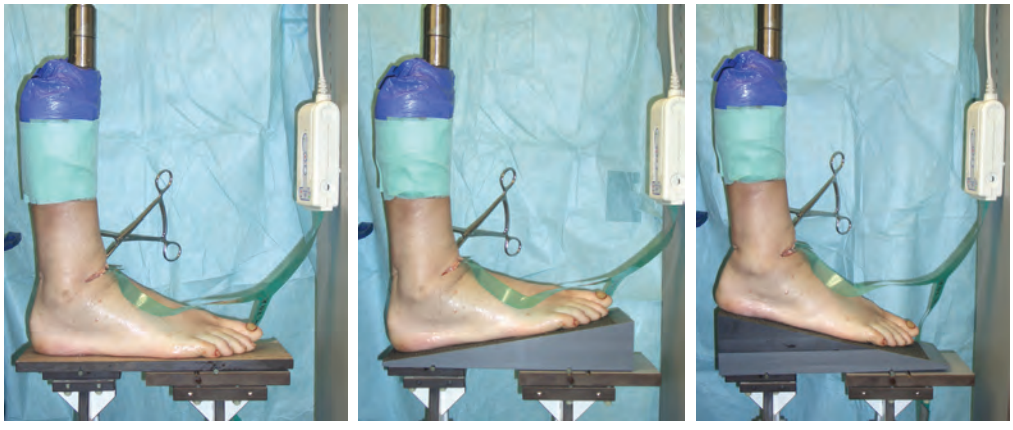


B C D

Figure 2. Pressure measurements. (A) Schematic drawing of the testing apparatus and data acquisition. The specimen with an intramedullary tibial nail (1) was mounted on a base-plate (2), with a rough surface, on a ball bearing (3). The ball bearing allowed anteroposterior translation (↔) of the foot in plantigrade position, but not in the plantarflexed and dorsiflexed positions. The force was applied by turning two handle-actuated lead screws (4) that gradually moved the base-plate upwards. The force transducers (5) were attached to a data acquisition system (6) that converted the output from the strain gages into force (N). A Tekscan sensor (7) was placed in the ankle joint and was connected via a USB interface (8) to a computer (9). In the testing apparatus, the specimens were loaded with a force of 1,500 N and with the ankle in the neutral position (B), 2,000 N in 10° of dorsiflexion (C), and 1,000 N in 14° of plantar flexion (D).

Pressure measurements

Intra-articular contact pressures were measured before and after implantation. One particular sensor was used for each specimen to correct for any minor differences between the sensors, and thus to permit reliable comparison of preimplantation and postimplantation pressures. Every test was performed twice and the average of both tests was used for data analysis.

According to the manufacturer's guidelines, each sensor was conditioned by applying three loads of 1,600 N with intervals of 30 s. The sensitivity was adjusted accordingly. The sensors were equilibrated and calibrated before every testing sequence. For equilibration, each sensor was inserted into a uniform pressure applicator (pressurized chamber) that was inflated to 6.5 bar. For calibration, a lever with weights attached was used, which allowed application of known forces to the sensor through a silicone interface. A two-point calibration method was applied by placing the sensor under the lever, between the metal and silicone parts, and loading it with forces of 750 N and 3,000 N for 30 s, with an interval of 3 min.

A transverse anterior incision was made, and the sensor was inserted in the ankle joint. It covered the talar dome and was sutured to the surrounding soft tissue. Digital photographs of the sensor positioning were taken at preimplantation testing to verify and ensure the same position during the postimplantation testing. The osteotomy was closed by placing a Weber bone clamp on the distal tibia, and was fixated by inserting two malleolar screws in the predrilled holes. The bone clamp was left in place to support the screw fixation during testing. An intramedullary nail was inserted into the tibial shaft, and the specimen was mounted on the testing apparatus.

An axial load was gradually applied for approximately 30 s, held in a stationary position for another 30 s, and then gradually released. After 30 s, a relatively stable condition is reached where changes in cartilage contact deformation and area are negligible.[248] To approximate forces and motion during the stance phase of gait, we applied loads of 1,500 N with the ankle in a neutral position, 2,000 N with the ankle in 10° of dorsiflexion, and 1,000 N with the ankle in 14° of plantar flexion. These loads represent 1.5 up to 3 times body weight and are within the range of previously reported biomechanical ankle studies.[80,236,264,286] Recordings were obtained with a sample frequency of 1 Hz. The data that were acquired 30 s after the maximum load had been reached were used for data analysis.

After the sensor was removed from the specimen and cleaned, it was again loaded under the calibration lever to check its accuracy. In one specimen, the sensor proved to be inaccurate; the sensor was replaced and the pressure testing was repeated.

Data analysis

I-scan software version 5.72 was used to qualitatively analyze the Tekscan-recorded pressure measurements. To determine the pressure (MPa) of the implant relative to the total pressure of the sensor, the area of the implant was selected manually. The same area was selected for the preimplantation measurements. In both measurements, the percentage of pressure over this area was calculated relative to the total pressure of the sensor (Figure 3).

In the case of normal distribution, values are presented as mean ± standard deviation and 95% confidence interval (CI). In the case of skewed distribution, values are presented as median and range.

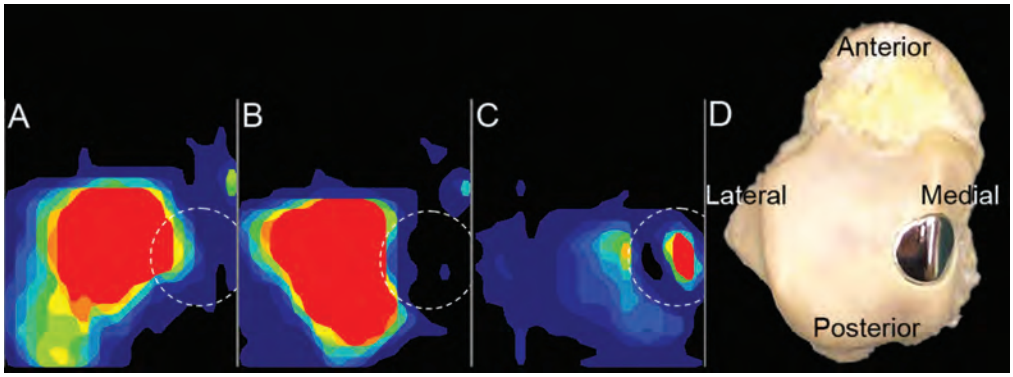


Figure 3. Contact pressures in the ankle joint before and after implantation of the prosthetic device. The circle indicates the position of the implant. The color range represents the spectrum of pressures (high: red; low: blue). (A) Contact pressure in a representative specimen (no. 8) in neutral position before implantation. (B) Contact pressure in the same specimen in neutral position after implantation. (C) Postimplantation contact pressure of the single specimen (no. 11) that showed the peak pressure over the implant (red), in the plantarflexed position. (D) An excised talus, viewed from superiorly, demonstrating the position of the implant.

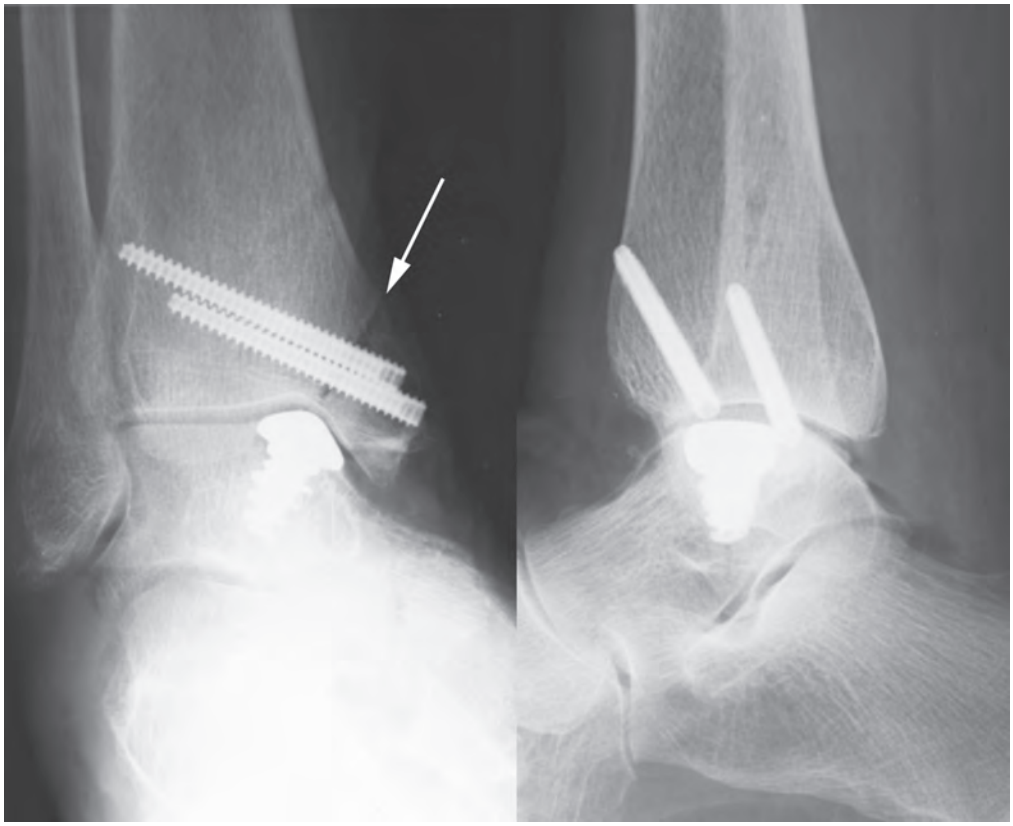


Figure 4. Radiographs of a right specimen (no. 7) with an implant. The arrow indicates the medial malleolar osteotomy fixated with two screws.

Table 1. Offset sizes and implantation levels of the implants (in mm).

Specimen no.	Offset size		Implantation level				
	AP	ML	Anterior	Posterior	Medial	Lateral	Mean[a]
1	1.5	5.0	1.07	0.48	-0.32	0.66	0.47
2	1.0	3.5	1.47	0.78	0.28	0.73	0.82
3	1.0	3.5	0.54	0.44	0.33	0.49	0.45
4	1.0	5.0	0.27	0.77	0.36	0.72	0.53
5	1.5	3.5	0.59	0.18	0.24	0.36	0.34
6	0.5	3.5	0.63	0.86	0.19	0.77	0.61
7	1.5	3.5	0.88	0.77	-0.72	0.65	0.40
8	1.0	3.5	0.76	0.17	-0.07	0.41	0.32
9	0.5	3.5	-0.20	0.56	-0.50	0.57	0.11
10	0.5	3.5	0.77	0.62	-0.08	0.29	0.40
11	1.5	4.5	0.45	0.32	0.59	0.59	0.49
	Mean[b] ± standard deviation		0.66 ± 0.43	0.54 ± 0.25	0.03 ± 0.40	0.57 ± 0.16	0.45 ± 0.18

Negative values represent protruding edges.
[a] Mean of anterior, posterior, medial, and lateral implantation level. [b] Mean of 11 specimens.
AP = anterior-posterior plane and ML = medial-lateral plane.

Results

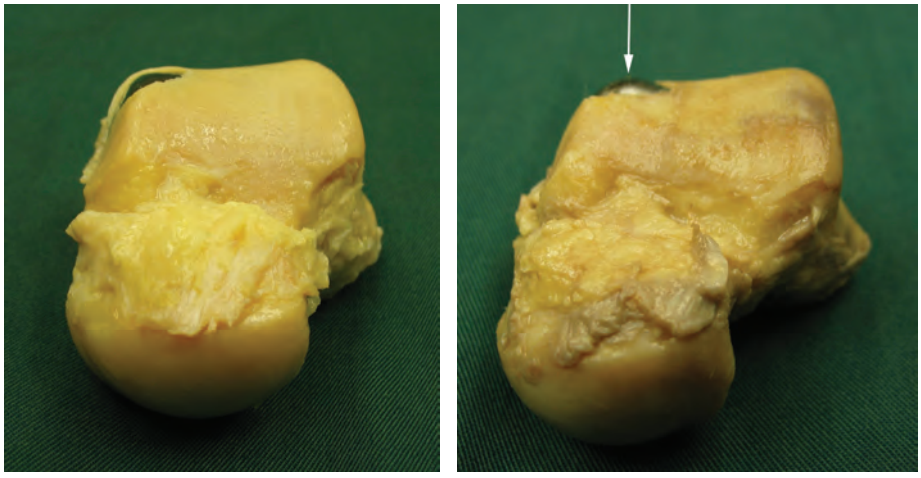
In all cases there was an appropriate articular component available, i.e., corresponding to the contact probe measurements taken during surgery (Figure 4). Six of the 15 offset sizes of the articular components were used. The required offset sizes ranged from 0.5 to 1.5 in the sagittal plane and from 3.5 to 5.0 in the coronal plane (Table 1).

The mean implantation level was 0.45 ± 0.18 mm (95% CI, 0.33 – 0.57) (Table 1). The lateral part of the implant, located on the talar dome, was measured to be recessed a mean of 0.57 ± 0.16 mm). The medial part of the implant, located on the medial talar facet, was the least recessed (mean, 0.03 ± 0.40 mm). The central part of the implant, as assessed by visual inspection, was recessed in 10 specimens and protruding in one specimen (no. 11) (Figure 5).

During the postimplantation pressure measurements, one specimen (no. 2) fractured (comminutive intra-articular distal tibial fracture), and it was excluded from pressure analysis. In two specimens (nos. 3 and 11) the preimplantation contact pressure was not measured, as the screw component had already been implanted during a pilot experiment.

Of the remaining eight specimens, in all positions combined, the median pressure of the prosthetic area before implantation was 3.3% (range, 0.02% – 18%) relative to the total contact pressure. After implantation, the median prosthetic pressure decreased to 0.09% (range, 0.02% – 13%) in these eight specimens. The highest median contact pressure was measured in the neutral position and the lowest in the plantarflexed position, both before and after implantation (Table 2).

The protruding implant (no. 11) resulted in an elevated contact pressure in the plantarflexed position (relative pressure, 44%) (Figure 3). In the neutral and dorsiflexed positions, the relative prosthetic pressures of this specimen were 13% and 0.92%, respectively (Table 2).



A B

Figure 5. Macroscopic anterior view of the implantation level after excision of the talus. (A) Representative specimen (no. 10) showing the implant slightly recessed (n = 10). (B) In one specimen (no. 11), the implant was protruding in the center (arrow).

Table 2. Contact pressures of the implant (%) relative to the entire sensor in the three joint positions.

Specimen no.	Neutral		10° dorsiflexion		14° plantar flexion	
	Pre	Post	Pre	Post	Pre	Post
1	3.7	0.14	4.1	0.06	0.10	0.10
2[a]	-	-	-	-	-	-
3[b]	-	0.04	-	0.02	-	0.11
4	0.08	0.12	1.7	0.06	0.04	0.12
5	18	13	14	13	11	3.2
6	0.49	0.84	0.55	2.2	2.6	0.04
7	3.0	0.04	0.02	0.02	6.5	0.04
8	5.8	0.08	3.2	0.16	1.7	0.08
9	17	0.26	18	0.21	3.3	0.03
10	6.9	0.02	4.2	0.02	2.2	0.05
11[bc]	-	13	-	0.92	-	44
Median[d]	4.8	0.13	3.7	0.11	2.4	0.07

[a] Fracture during loading. [b] No measurements before implantation. [c] Protruding central implant. [d] Median values of specimens 1 and 4 through 10.
Pre = before implantation and Post = after implantation.

Discussion

In this study, the novel metallic inlay implant was investigated before clinical use. The range of available offset sizes was found to be appropriate for the variety of ankle specimens used in this study. The prosthetic device was implanted on average 0.45 mm (95% CI, 0.33 – 0.57 mm) below the articular cartilage level. With this implantation level, excessive

pressures on the opposite tibial cartilage were prevented.

There have been few studies dealing with the level of implantation of metallic implants and its effect on opposing cartilage. In a comparative rabbit study, Custers et al. showed that protruding implantation of metal plugs in the femoral condyle caused the most damage to the opposite tibial cartilage, and that flush implantation caused the least damage.[90] Their deep implantations were below the level of the subchondral plate and therefore cannot be compared with the average implantation level in our study. Becher et al. compared implantation levels of a femoral condyle HemiCAP using human cadaver specimens.[43] They concluded that protruding implantation led to substantially increased peak contact pressure, as also occurred in our single protruding implantation (specimen no. 11). However, the knee and ankle cannot be compared because the ankle joint is more congruent and its cartilage has different mechanical and biochemical properties.[354,399]

The protruding central part of the implant in specimen no. 11 was due to an elevated screw rather than an inappropriate articular component. The level of the screw determines the central height, while the offset sizes of the articular component determine the peripheral height. It is thus crucial to implant the screw to a precise level, which is indicated by a mark on the screwdriver. The level of the implanted screw can be checked initially by placing a trial button, and adjusted if necessary. The availability of higher offset sizes allows for a recessed peripheral implantation even in the presence of a relatively high screw.

The implantation level of 0.5 mm below the cartilage surface aimed at in this study was based on the biomechanical properties of talar cartilage.[248,444]. Li et al. measured a peak contact strain of 30% ± 6.1% after 30 s of loading, using magnetic resonance and dual-orthogonal fluoroscopic imaging.[248] Similarly, Wan et al. measured a peak contact strain of 35% ± 7.3% in human subjects with a mean medial talar dome cartilage thickness of 1.42 ± 0.31 mm.[444] To compensate for the compressible property of cartilage, the incompressible metallic implant was aimed 0.5 mm (i.e., 35% of 1.42 mm) below the cartilage surface in our study. The average implantation level achieved, 0.45 mm below the level of the articular cartilage, corresponds to 31% (95% CI, 23% – 40%) of 1.42 mm.

In the event that the implant would be non-weight bearing due to deep implantation, the remaining weight-bearing area of the talar dome has been shown to be capable of carrying the loads without any statistically significant alteration in contact pressure.[80]. In particular, the periphery of the implant cap should be recessed because "edge-loading" may result in a poor outcome.[43,222]. The lateral part of the implant can be considered to be crucial because it is located on the weight-bearing talar dome articulating with the tibial plafond. Here, the implant was recessed in all cases (mean, 0.57 mm) with little variability (standard deviation, 0.16 mm). In contrast, the medial part of the implant is located on an area of the talus that typically bears less weight, i.e., the medial talar facet. Hence, a protruding implantation on the medial side is possibly less harmful to the opposite cartilage of the medial malleolus.

Our study has limitations. We used cadaver specimens of elderly individuals (aged 66 – 89 years), whereas patients suffering from an OCD are often young adults. The cartilage of our specimens may have undergone degenerative changes with aging. The ankle joint is not, however, prone to osteoarthritic changes during aging,[85] and there is no correlation between the thickness of talar cartilage and age.[354] Furthermore, the specimens in our study were macroscopically graded; only those with intact cartilage were included.

Contact pressures were measured under static loading, while dynamic or cyclic loading may be advocated because of its supposedly better imitation of real life. We applied static loading because more cartilage deformation can be obtained by one continuous load than by short-time loads with intervals.[183] Because there is more cartilage deformation with static loading, any excessive contact pressure due to elevated implantation might be detected more adequately. This implies that, if tested under dynamic loading, a higher implantation level might be erroneously accepted. To imitate the stance phase of gait, the joint was loaded in three positions that correspond to the mean sagittal ankle motion with corresponding forces.[367]

The loads were applied to the tibia, as was done in previous studies.[253,264,323] The real-life situation might have been better imitated by also loading the fibula, which transmits 7% of the total force through the lower leg.[157] However, loading the fibula would probably not have had any notable effect on the results because the pressure distribution would have shifted slightly to the lateral side,[389] with minor effects on the medially located implant.

Variability among specimens is a common finding in cadaver experiments.[276]. The contact pressure of the prosthetic area before implantation ranged from 0.02% to 18% in the cadavers we used (see Table 2). This variability does not affect the conclusions, as each talus served as its own control.

Possible inaccuracies of Tekscan pressure-sensitive sensors are their sensitivity to moisture and temperature, wrinkling, and change of their position during loading.[43,373]. By testing in a single lab, any inaccuracy due to difference in moisture or temperature was minimized. To detect inaccuracy due to wrinkling, the sensor was inspected after a loading sequence and checked under the lever arm loading system. It was replaced in one specimen. Changes in sensor position were minimized by taking digital photographs at the first testing sequence, which we used for verification of positioning at the second sequence.

Our findings form a first basis for clinical use of the implant, but its clinical effectiveness remains to be investigated. Other designs of this prosthetic implant have been used clinically for different joint surfaces, including the first metatarsal head,[180] femoral head,[437] humeral head,[404] and patella.[95] Although the short-term clinical outcome of these designs is promising, it remains to be investigated whether the implant is effective for the treatment of OCDs of the talus, in terms of reducing pain and preventing cyst formation.

In conclusion, our study shows that accurate and reproducible implantation of this novel metallic implant can be achieved, preventing excessive prosthetic pressure. The results suggest that the implant can be used clinically in a safe way, but the effectiveness and safety of this treatment option should be evaluated in a clinical study.

Acknowledgments

The authors thank the personnel of the Pathology Department for their kind hosting during the experiments.

Chapter 10

Treatment of secondary osteochondral defects of the talus with a metal resurfacing inlay implant: a prospective study

Christiaan J.A. van Bergen
Inge C.M. van Eekeren
Mikel L. Reilingh
Inger N. Sierevelt
C. Niek van Dijk

Bone & Joint Journal
in press.

Abstract

The aim of this study was to evaluate the clinical effectiveness of a metal resurfacing inlay implant for osteochondral defects of the medial talar dome after failed prior surgical treatment. Twenty consecutive patients, aged 20 to 60 years (mean, 38 years), were prospectively studied for 2 to 5 years (mean, 3 years). There was statistically significant reduction of pain in each of four situations (i.e., rest, walking, stair climbing, and running; $p \leq 0.01$). The median American Orthopaedic Foot and Ankle Society ankle-hindfoot score improved from 62 (interquartile range, 46 – 72) preoperatively to 87 (interquartile range, 75 – 95) at final follow-up ($p < 0.01$). The Foot and Ankle Outcome Score improved on all subscales ($p \leq 0.03$). The mean Short Form-36 physical component scale improved from 36 (range, 23 – 50) preoperatively to 45 (range, 29 – 55) at final follow-up ($p < 0.01$); the mental component scale did not change significantly. On radiographs, progressive degenerative changes of the opposing tibial plafond were observed in two patients. One patient required additional surgery for the osteochondral defect. This study shows that the metal implantation technique is a promising treatment for osteochondral defects of the medial talar dome after failed previous treatment.

Introduction

Approximately 63% of osteochondral defects (OCDs) of the talus are located on the medial talar dome.[322,458] These medial defects are generally deep and cup-shaped.[322] An OCD may sometimes heal and stabilize, but often progresses to a cystic lesion causing deep ankle pain on weight bearing, prolonged swelling, diminished range of motion, and synovitis.[434]

Arthroscopic debridement and bone marrow stimulation is considered the primary treatment.[458] Current secondary treatment options include osteochondral autograft transfer, autogenous bone graft, and autologous chondrocyte implantation.[458] However, these techniques are associated with donor site morbidity and limited availability or involve two-stage surgery.[39,312,407]

In order to treat OCDs of the medial talar dome after failed primary treatment, a metal resurfacing inlay implant (HemiCAP®, Arthrosurface Inc., Franklin, MA, USA) has been developed.[17,411] The implant comprises two components: a cobalt-chromium modular articular component, with a diameter of 15 mm, and a titanium cannulated screw, which are connected together via a taper interlock. Fifteen incremental offset sizes of the articular component are available, based on the surface geometry of the medial talar dome.[411]

Promising short-term clinical results have been reported of other designs of the implant for the treatment of various human joints.[95,180,404,437] Two biomechanical cadaveric studies provided foundations for use of the talus implant in the ankle joint.[17,411] These studies showed that recessing the implant slightly relative to the adjacent cartilage level leads to acceptable contact stresses in the talocrural joint and is beneficial compared to leaving it proud.[17,411]

The aim of this study was to evaluate the clinical effectiveness of the metal implantation technique for OCDs of the medial talar dome after failed previous surgery.

Methods

This prospective case series was approved by the local Medical Ethics Committee. We included

patients with an OCD of the medial talar dome, with the largest diameter between 12 and 20 mm on computed tomography, and persistent complaints >1 year after prior surgical treatment. Exclusion criteria were: age <18 years, defect size >20 mm, ankle osteoarthritis grade III,[426] concomitant ankle pathology (tibial osteochondral defect, ankle instability, or ankle fracture), advanced osteoporosis, infection, a known allergy to implant material, and diabetes mellitus (because diabetes is associated with increased risk of infection as well as softer and more permeable talar cartilage).[25] All patients provided informed consent.

Computed tomography scans were obtained preoperatively to measure the size in three directions and grade the defect according to the modified Berndt and Harty classification.[49,349] In addition, the defects were graded intraoperatively with use of a macroscopic classification system.[377]

Operative technique

The senior author performed all surgical procedures using a standard technique (Figure 1).[329] An oblique medial malleolar osteotomy was created to expose the talus. The osteotomy was aimed at the intersection between the medial malleolus and the tibial plafond, which was identified with use of an aiming probe, and directed 30° relative to the long tibial axis.[413,414]

The OCD was debrided until a healty cartilage rim remained. A guide pin was placed into the center of the defect, perpendicular to the curvature of the medial talar dome, with use of a drill guide. The cannulated screw was predrilled and inserted. A contact probe was used to determine the radius of curvature in the sagittal and coronal planes to allow for a precise fit of the articular component to the existing articular surface. A matching reamer prepared the site for placement of the articular component. A sizing trial cap with corresponding offsets allowed for final verification of proper fit. The selected articular component was impacted on the screw, thereby engaging the taper interlock. Sufficient recession of the implant was determined by visual inspection. The osteotomy was reduced and fixated with two lag screws in predrilled holes.

The postoperative management was initiated with a plaster cast for 2 weeks, followed by a detachable plaster cast or brace (Walker, Össur, Son en Breugel, the Netherlands) for 4 weeks. During this period, non—weight-bearing sagittal range-of-motion exercises were prescribed. Radiographs were obtained at 6 weeks after surgery to confirm consolidation of the malleolar osteotomy. Physical therapy was then prescribed to assist in functional recovery and progress to full weight bearing in approximately 1 month.

Outcome assessment

The patients were assessed preoperatively and at 2 weeks, 6 weeks, 3 months, 6 months, and annually postoperatively. Authors not involved in the surgical procedures assessed the patients and completed specially designed case report forms.

The primary outcome measure was the numeric rating scale (NRS) of pain. The NRS consists of an 11-point scale, which represents the spectrum of no pain (0 points) to the worst pain imaginable (10 points).[339] Four numeric rating scales were taken, i.e., pain at rest, during walking, during stair climbing, and during running. NRS during running was not assessed in patients that could not or did not run at any time point.

Secondary outcome measures were assessed preoperatively and at each follow-up visit starting 6 months postoperatively, and included the American Orthopaedic Foot and Ankle Society (AOFAS) ankle-hindfoot score, Foot and Ankle Outcome Score (FAOS),

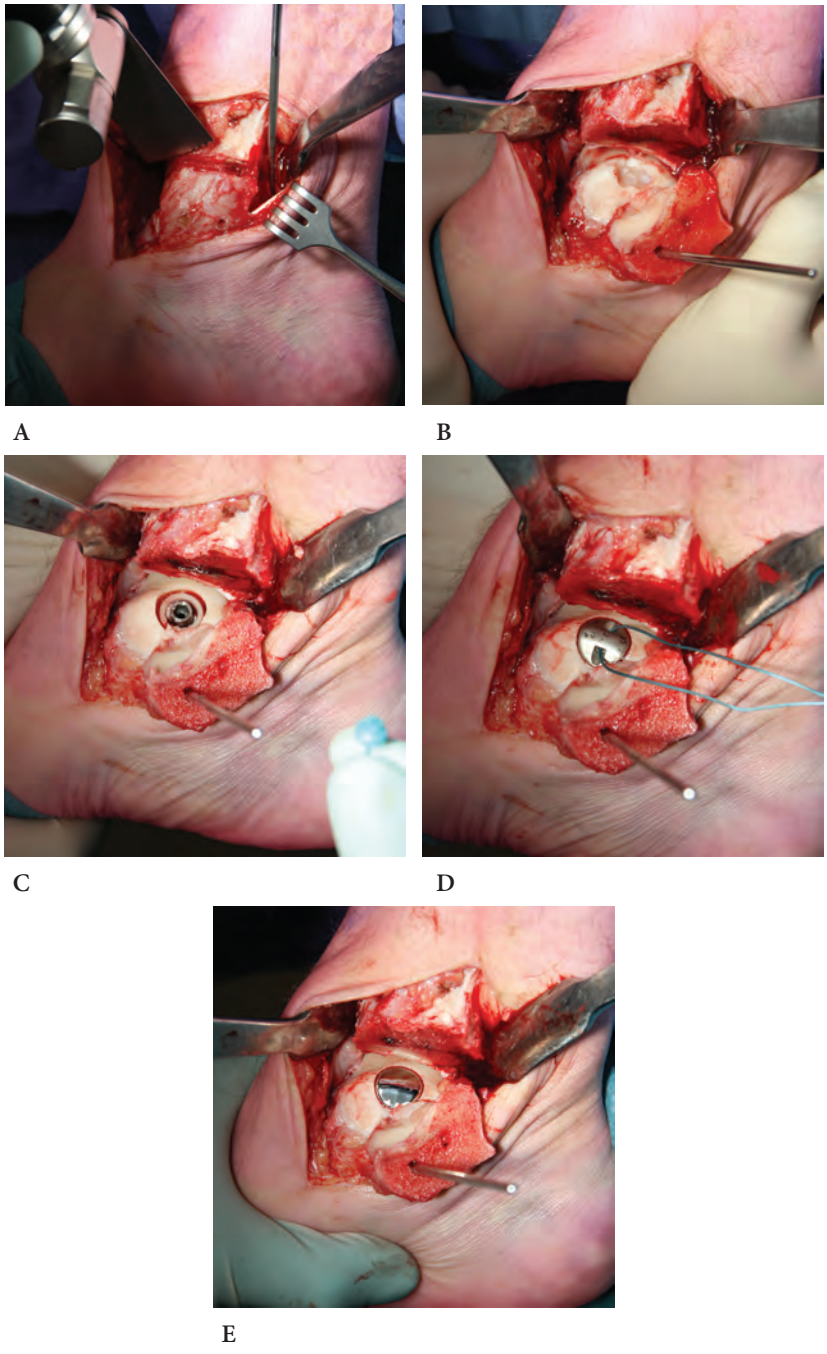


Figure 1. Intraoperative photographs of a right ankle. A medial malleolar osteotomy was performed to expose the medial talar dome (A). The osteochondral defect was debrided (B). The screw was inserted in the center of the defect (C). A trial articular component was placed on the screw (D). The definitive articular component was engaged on the screw (E).

and Short Form-36 (SF-36). The AOFAS is a 100-point score, with a subjective and an objective component, which devotes 40 points to pain, 50 points to function, and 10 points to alignment.[217] It is frequently used in the assessment of foot and ankle therapy, and the subjective component has been validated.[192] The FAOS is a validated subjective questionnaire consisting of five subscales: pain, other symptoms (e.g., swelling, locking, mobility), function (activities of daily living), sport and recreational activities, and foot- and ankle-related quality of life.[336] Each subscale's highest possible score is 100. The SF-36 is a validated outcome measure to assess general quality of life.[7] The normative value of the Dutch population is 49.2 for the physical component scale and 50.7 for the mental component scale.[7]

Complications were assessed at each follow-up visit by a patient interview and physical examination. Furthermore, the time needed to resume work and sports was recorded. Patients indicated the sport level as follows: I, high competitive sportsperson; II, well-trained and frequently sporting; III, sometimes sporting; or IV, not sporting. The use of analgesics was also recorded. At 2 years of follow-up and annually thereafter, patients indicated whether they would undergo the procedure again, and whether they would recommend the procedure to friends and family.

Radiography

Weight-bearing radiographs (anteroposterior mortise and lateral views) were obtained at all follow-up visits as of 6 weeks postoperatively. The radiographs were reviewed for evidence of implant loosening (periprosthetic osteolysis, subsidence, migration, and disengagement), for malunion or nonunion of the malleolar osteotomy, and for degenerative changes of the opposite distal tibia (subchondral sclerosis, cyst formation, and joint space narrowing).

Statistical analysis

A power analysis, performed before the start of the study, indicated that a sample size of 20 patients would detect a clinically important mean pain change of 1 point on the NRS, based on a standard deviation of 1.5, with $\alpha = 0.05$ and a power of 80%.[339]

Statistical analyses were performed with use of SPSS software (version 19.0; Chicago, IL, USA). Categorical data are presented as frequencies. Continuous data are presented as means with ranges or as medians with interquartile ranges (IQR), depending on their distribution. One-way repeated-measures analyses of variance (ANOVA) were performed to determine differences in mean scores at different time points for the outcomes with a normal distribution (NRS-rest, NRS-walking, NRS-stair climbing, FAOS, and SF-36). In case of significance ($p < 0.05$), post-hoc pairwise comparisons were performed using a Bonferroni correction. The assumptions of normality and sphericity were checked with use of the Shapiro-Wilk test and Mauchly's test, respectively. Due to the skewed distribution of the NRS-running and AOFAS, these scores were analyzed using the Friedman's two-way analysis of variance by ranks. Post-hoc pairwise comparisons of these outcome measures were performed with use of Wilcoxon signed-rank tests with Bonferroni correction to adjust for multiple comparisons. The SF-36 scales were compared with the normative data for the Dutch population with use of the Student's t-test.

Results

Twenty-four patients received the implant between October 2007 and November 2010. Four were excluded from the study because they had no previous surgery for the OCD

(two patients), had a combined procedure (one patient), or had diabetes mellitus (one patient). Twenty patients were included in the study. The mean duration of follow-up was 3 years (range, 2 – 5 years). No patients were lost to follow-up. There were 13 female and seven male patients, with a mean age of 38 years (range, 20 – 60 years). The left ankle was affected in 13 patients. The median body mass index was 26.1 kg/m^2 (IQR, 24.2 – 27.0 kg/m^2)

Eight patients had one, nine patients had two, and three patients had three prior operations. These included one to three procedures of arthroscopic or open debridement and bone marrow stimulation in all cases; cancellous bone grafting in four cases; and osteochondral screw fixation in one case. Five patients received additional hyaluronic acid injections. The median time between the last procedure and the metal implantation was 2 years (IQR, 2 – 6 years).

The mean defect size was 15 mm (range, 11 – 20 mm) in the anteroposterior direction, 10 mm (range, 8 – 14 mm) in the mediolateral direction, and 9 mm (range, 4 – 16 mm) in the craniocaudal direction. On radiographs, one defect was classified as stage III (complete avulsion of a fragment), one as stage IV (displaced fragment), and 18 as stage V (cystic lesion). Intraoperatively, two defects were macroscopically classified as grade II (softening or fibrillation of the cartilage), five as grade III (fraying of the cartilage), 10 as grade IV (detached fragment), and three as grade V (displaced fragment). Sixteen defects were located on the centromedial talar dome and four on the posteromedial talar dome.

Outcomes

The NRS-pain improved significantly in all four situations (Table 1 and Figure 2). For example, repeated-measures ANOVA determined that the mean NRS-walking differed significantly between time points ($F_{(4, 76)}$ = 16.0, p <0.01). Post-hoc pairwise comparisons using Bonferroni correction revealed that the NRS-walking was significantly decreased at all postoperative time points compared to the preoperative situation (p <0.01 to p = 0.05).

The median AOFAS improved from 62 (IQR, 46 – 72) preoperatively to 75 (IQR, 68 – 87) at 6 months, 87 (IQR, 76 – 94) at 1 year, and 87 (IQR, 75 – 95) at the final follow-up (p <0.01). Post-hoc tests revealed significant differences at 1 year and at the final follow-up compared to preoperatively (p <0.01).

Table 1. Numeric rating scale pain

Situation	Rest	p*	Walking	p*	Stair climbing	p*	Running	p***
	$F_{(4, 76)}$ = 6.1; p <0.01**		$F_{(4, 76)}$ = 16.0; p <0.01**		$F_{(4, 72)}$ = 17.6; p <0.01**		p = 0.01****	
Preoperative	3.6 (0 - 8)		6.7 (4 - 9)		6.6 (4 - 10)		10.0 (9 - 10)	
3 months	2.4 (0 - 8)	1.00	4.4 (1 - 8)	0.05	4.6 (0 - 8)	0.24	7.0 (5 - 10)	0.10
6 months	1.7 (0 - 6)	0.09	3.3 (0 - 9)	<0.01	2.8 (0 - 7)	<0.01	6.0 (3 - 10)	0.03
1 year	1.3 (0 - 7)	0.01	2.3 (0 - 7)	<0.01	2.2 (0 - 6)	<0.01	3.0 (1 - 6)	<0.01
Final	1.1 (0 - 5)	0.01	2.8 (0 - 7)	<0.01	2.5 (0 - 7)	<0.01	4.5 (1 - 7)	<0.01

The values are given as the mean, with the range in parentheses (rest, walking, stair climbing) or as the median, with the interquartile range in parentheses (running).

* Bonferroni-adjusted p-value of pairwise comparison with the preoperative NRS

** Repeated-measures ANOVA

*** Wilcoxon signed-rank test

**** Friedman's two-way analysis of variance by ranks

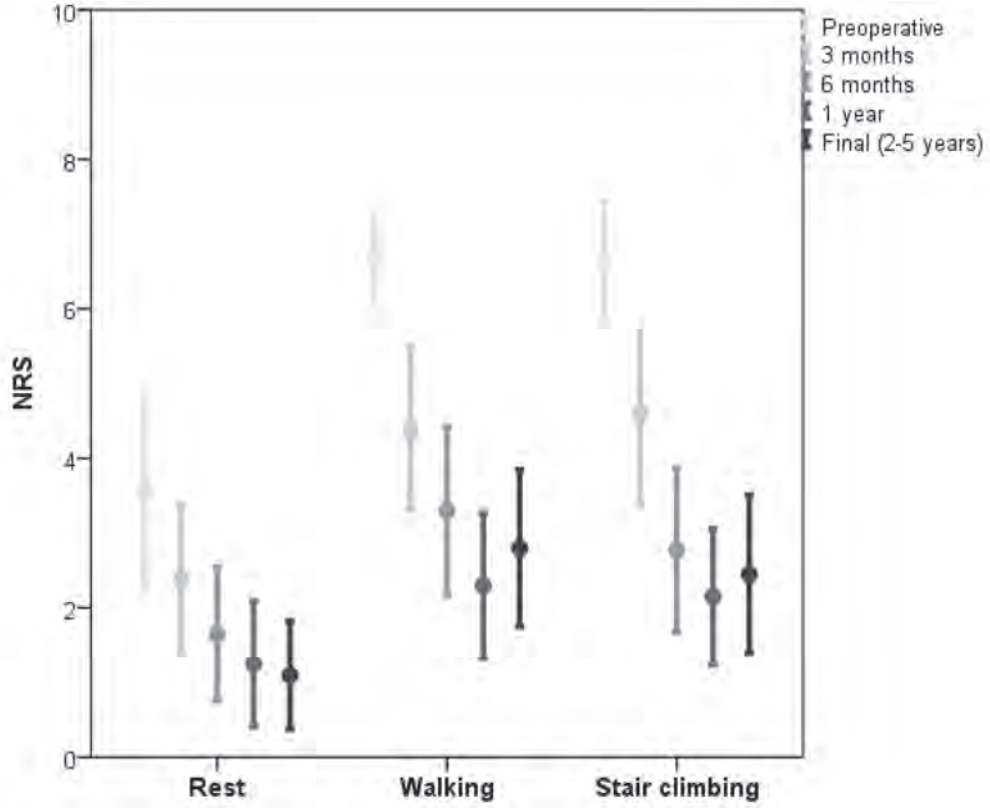


Figure 2. Graph showing the mean and 95% confidence interval for each situation of the numeric rating scale (NRS) pain from preoperatively to the final follow-up ($p < 0.01$). The NRS-running is presented as median and interquartile range (see Table 1) due to the skewed distribution.

The FAOS improved significantly on all subscales (Figure 3). Post-hoc pairwise Bonferroni-adjusted comparisons revealed statistically significant differences between preoperative scores and most postoperative scores (Table 2).

The mean SF-36 physical component improved from 36.2 (range, 22.8 – 50.3) preoperatively to 42.2 (range, 21.0 – 52.3) at 6 months ($p = 0.05$), 44.0 (range, 28.5 – 57.4) at 1 year ($p = 0.01$), and 45.0 (range, 28.6 – 54.6) at final follow-up ($F_{(3, 51)} = 6.4$; $p < 0.01$). The SF-36 mental component did not change significantly; the mean score was 53.0 (range, 21.9 – 67.9) preoperatively, 50.6 (range, 34.7 – 62.1) at 6 months, 52.8 (range, 39.8 – 60.3) at 1 year, and 54.3 (range, 24.9 – 66.5) at final follow-up ($F_{(3, 51)} = 2.5$; $p = 0.07$). Neither the final physical nor the mental component differed significantly from the population norm.[7]

Preoperatively, 16 patients worked. All 16 patients resumed their work during follow-up. The median time to return to work was 8 weeks (IQR, 4 – 23 weeks).

Twelve patients used to play sports before their ankle symptoms had started. Only three were able to play sports preoperatively. Eleven of these 12 patients resumed sports during follow-up. The level of sports decreased in five patients, was equal in four, and improved in

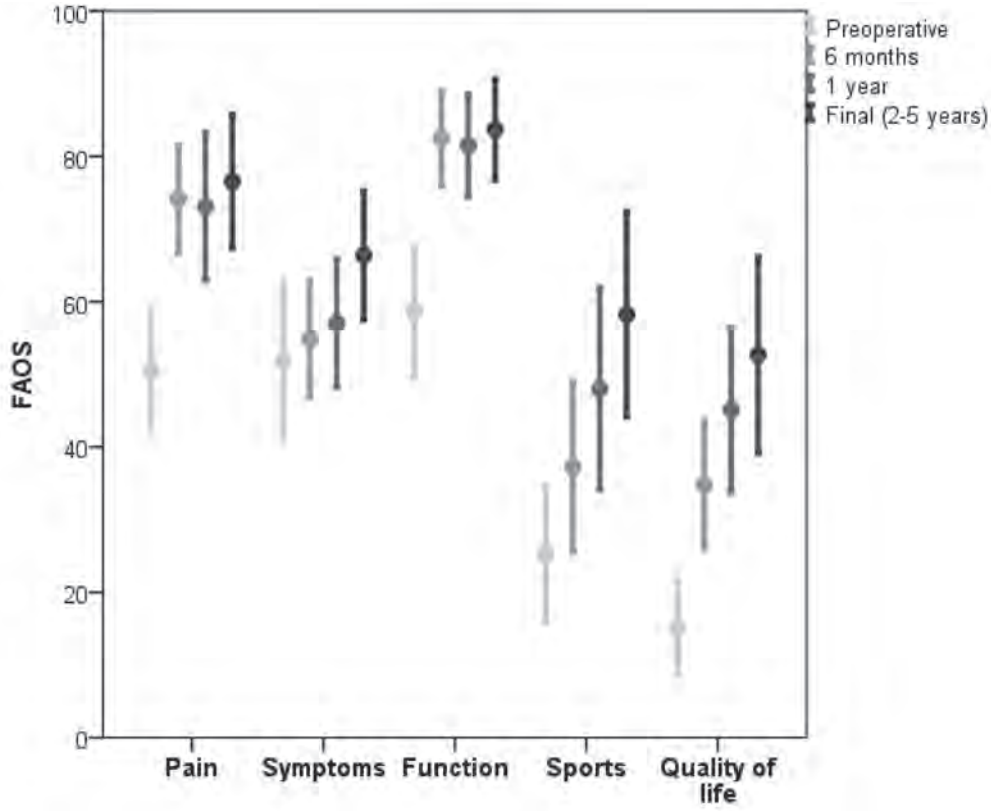


Figure 3. Graph showing the mean and 95% confidence interval for each component of the Foot and Ankle Outcome Score (FAOS) from preoperatively to the final follow-up. The improvement of each subscale was statistically significant ($p \leq 0.03$).

two, as compared to the presymptoms level. Two additional patients, who did not play sports before the symptoms, started playing sports during follow-up. The median time to resumption of sports was 17 weeks (IQR, 8 – 27 weeks).

Seven patients used analgesics preoperatively. During follow-up, analgesics were used by none of the patients at 6 weeks and 3 months, by one at 6 months, by three at 1 year, and by none at the final follow-up.

At the final follow-up, 18 patients (90%) indicated that they would undergo the procedure again and that they would recommend the procedure to friends and family.

Radiography

There were no signs of implant loosening (Figure 4). The medial malleolar osteotomy healed in all cases by 6 weeks. One patient showed subchondral sclerosis of the opposing tibial plafond at final follow-up. Another patient had a progressive subchondral cyst of the opposite tibial plafond.

Complications and reoperations

Some patients had a temporary area of numbness about the scar, which resolved within months. One patient had a superficial wound infection,

Table 2. Foot and ankle outcome score

Subscale	Pain	p*	Symptoms	p*	Function (ADL)	p*	Sport	p*	Quality of life	p*
	$F_{(3, 54)} = 13.5$; p <0.01**		$F_{(3, 54)} = 3.2$; p = 0.03**		$F_{(3, 54)} = 19.2$; p <0.01**		$F_{(3, 54)} = 11.5$; p <0.01**		$F_{(3, 54)} = 21.6$; p <0.01**	
Preoperative	50.5 (14 - 78)		52.0 (11 - 96)		58.6 (15 - 85)		25.4 (0 - 70)		15.2 (0 - 44)	
6 months	74.1 (56 - 100)	<0.01	54.9 (21 - 89)	1.00	82.5 (43 - 100)	<0.01	37.2 (0 - 75)	0.20	34.8 (0 - 63)	<0.01
1 year	73.1 (39 - 100)	<0.01	57.1 (25 - 91)	1.00	81.5 (54 - 100)	<0.01	48.0 (10 - 100)	<0.01	45.1 (13 - 88)	<0.01
Final	76.6 (25 - 100)	<0.01	66.4 (21 - 96)	0.07	83.7 (46 - 100)	<0.01	58.3 (5 - 100)	<0.01	52.7 (6 - 100)	<0.01

The values are given as the mean, with the range in parentheses.
* Bonferroni-adjusted p-value of pairwise comparison with the preoperative score
** Repeated-measures ANOVA
ADL = activities of daily living.

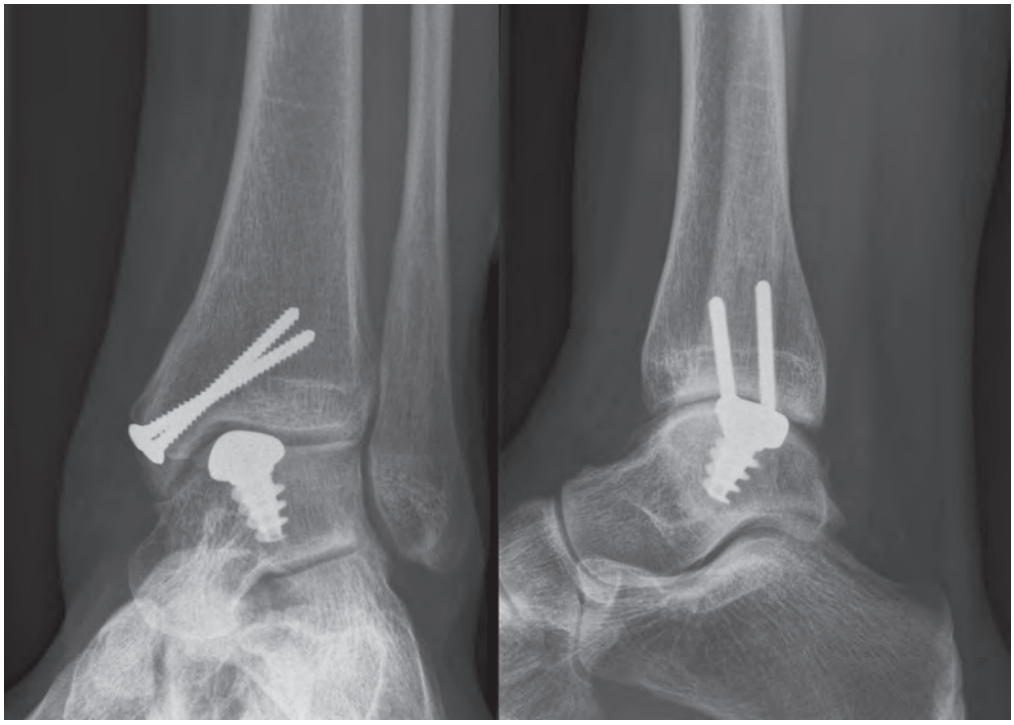


Figure 4. Mortise view and lateral weight-bearing radiographs of a left ankle 3 years postoperatively. Sufficient recession of the implant was confirmed intraoperatively.

which was effectively treated with oral antibiotics. The medial malleolar osteotomy entered the posterior tibial plafond in one patient, but healing of the osteotomy was uneventful.

There were a total of seven additional surgical procedures in six patients. One patient required a lateral displacement calcaneal osteotomy after 26 months because of persistent deep ankle pain and subtle varus malalignment. One patient underwent arthroscopic treatment of anterior ankle impingement. In five patients the malleolar screws were removed after a mean of 15 months (range, 8 – 26 months) due to a prominent screw and/or tenderness on

palpation. These patients had NRS scores similar to the complete study group (mean final NRS-rest, walking, stair climbing, and running of 1.2, 2.8, 3.2, and 4.3, respectively).

Discussion

Treatment of OCDs by focal metal resurfacing implants is relatively new.[54,95,180,404,437] This prospective study describes the results of a metal implant designed for the talus. The presented outcomes show that patients generally benefit from the procedure. This was evidenced by the statistically significant improvement in almost all outcome measures and high rates of work and sport resumption. Progressive degenerative changes were present on radiographs of two patients. One patient required a lateral displacement calcaneal osteotomy because of persistent pain. Ninety percent of the patients indicated that they would undergo the procedure again.

We theorize that the effectiveness of the resurfacing implant is simply based on the mechanism of filling and coverage of the defect. Increased fluid pressure from the joint into the subchondral bone has been described as the cause of pain and of progressive subchondral cysts in untreated defects.[330,434] This process possibly is stopped by filling and covering the defect.

The study population represents a therapeutic challenge. The OCDs were cystic, relatively large, and had failed prior surgical treatment. Alternative treatment methods for these cases include osteochondral autograft transfer and cancellous bone grafting.[458] Both can lead to satisfactory clinical results, but disadvantages include donor site morbidity in up to 50%, talar surface mismatching, and limited availability.[122,343,407] Furthermore, recurrent lesions, cartilage degeneration, and discontinuity of the subchondral bone plate have been observed after osteochondral autograft transfer,[407] as well as inferior results in the treatment of secondary OCDs.[193] Autologous chondrocyte implantation is another alternative but involves two surgical procedures and is more suitable for superficial cartilage defects than for cystic lesions.[39]

Massive, refractory OCDs can be treated with an allograft, ankle arthrodesis, or total ankle prosthesis. Allografts are not recommended for focal defects, because of the loss of viability and stability in approximately one-third of the grafts.[168] Ankle arthrodesis or prosthesis are more definite solutions for a recurrent OCD but are rather not used in these relatively young patients because of sacrifice of ankle motion and limited durability, respectively. If the metal implant should fail in the long term, it can be removed and the ankle joint can still be fused or replaced.

Strengths of this study are the prospective methodology, completeness of follow-up, and the use of various validated outcome measures. Limitations include the relatively small series, absence of a control group, and lack of long-term follow-up. A limitation of the implant is the fixed diameter of 15 mm. This size is based on the finding that primary arthroscopic treatment is generally successful for defects up to 15 mm in diameter.[82] If the secondary OCD is smaller than 15 mm, some healthy cartilage is sacrificed for implantation of the metal device. In contrast, if the defect is larger, a part of it cannot be covered by the implant. In the latter situation, we expect the remainder of the OCD to be filled by fibrocartilaginous tissue.

In conclusion, the metal implantation technique is a promising treatment for OCDs of the medial talar dome after failed previous treatment. Although the results of this study are encouraging, more patients, longer follow-up, and preferably a control group may determine the place of the implant in the treatment of osteochondral talar defects.

Chapter 11

Direction of the oblique medial malleolar osteotomy for exposure of the talus

Christiaan J.A. van Bergen
Gabriëlle J.M. Tuijthof
Inger N. Sierevelt
C. Niek van Dijk

Archives of Orthopaedic and Trauma Surgery
2011;131(7):893-901.

Abstract

Introduction

A medial malleolar osteotomy is often indicated for operative exposure of posteromedial osteochondral defects and fractures of the talus. To obtain a congruent joint surface after refixation, the oblique osteotomy should be directed perpendicularly to the articular surface of the tibia at the intersection between the tibial plafond and medial malleolus. The purpose of this study was to determine this perpendicular direction in relation to the longitudinal tibial axis for use during surgery.

Materials and methods

Using anteroposterior mortise radiographs and coronal computed tomography (CT) scans of 46 ankles (45 patients) with an osteochondral lesion of the talus, two observers independently measured the intersection angle between the tibial plafond and medial malleolus. The bisector of this angle indicated the osteotomy perpendicular to the tibial articular surface. This osteotomy was measured relative to the longitudinal tibial axis on radiographs. Intraclass correlation coefficients (ICCs) were calculated to assess reliability.

Results

The mean osteotomy was 57.2° ± 3.2° relative to the tibial plafond on radiographs and 56.5° ± 2.8° on CT scans. This osteotomy corresponded to 30.4° ± 3.7° relative to the longitudinal tibial axis. The intraobserver (ICC, 0.90 – 0.93) and interobserver (ICC, 0.65 – 0.91) reliability of these measurements were good to excellent.

Conclusion

A medial malleolar osteotomy directed at a mean 30° relative to the tibial axis enters the joint perpendicularly to the tibial cartilage, and will likely result in a congruent joint surface after reduction.

Introduction

A medial malleolar osteotomy is an established approach for the operative treatment of medial osteochondral defects of the talar dome and fractures of the talar body.[296,351,390,461] Ray and Coughlin in 1947 first described a transverse osteotomy.[325] Different techniques have been described since then, including inverted V,[302] oblique,[366] crescentic,[442] step-cut,[13] and inverted U osteotomy[309] (Figure 1).

The oblique osteotomy is an established technique that is used by many surgeons. There are various advantages, including the relatively simple technique, excellent exposure of the talus, preservation of the deltoid ligament, and optimal screw compression.[351] This technique has been shown to provide reproducibly perpendicular access to medial talar lesions treated with osteochondral autograft transfer or metal implants.[167,176,411] Most surgeons agree that the osteotomy should be aimed at the intersection

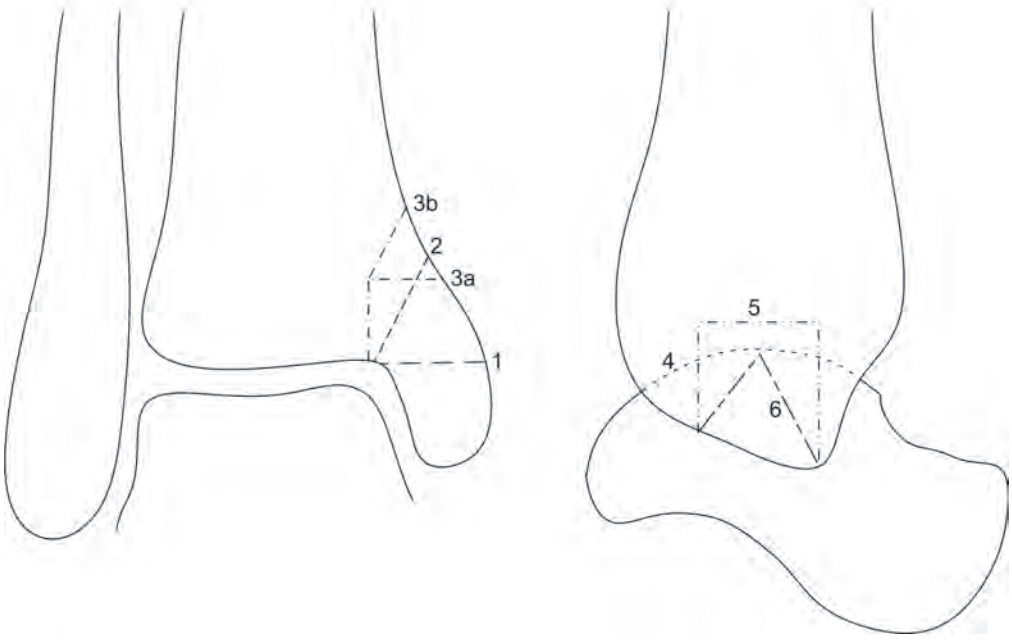


Figure 1. Anteroposterior (left) and lateral (right) drawings of an ankle, showing the different medial malleolar osteotomy techniques for exposure of the talus as described in the literature. (1) Transverse osteotomy; (2) Oblique osteotomy; (3a) Step-cut osteotomy; (3b) Modified step-cut osteotomy; (4) Crescentic osteotomy; (5) Inverted U-osteotomy; (6) Inverted V-osteotomy.

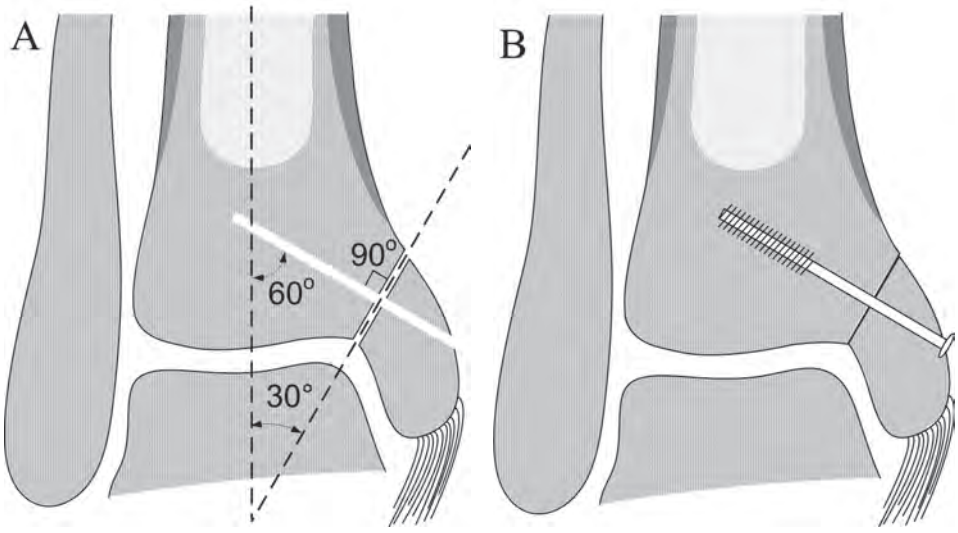


Figure 2. Schematic drawings of the correct technique in which there is no articular step off after screw fixation through the predrilled screw holes. After predrilling the screws at 60° in relation to the tibial axis, the osteotomy is made at 30° in relation to the tibial axis (A). A slice of bone is sacrificed when performing the osteotomy due to the saw blade thickness. Introduction of the compression screws through the predrilled channels will result in a smooth joint surface (B).

between the tibial plafond and the articular facet of the medial malleolus.[40,281,350,351] Failure to exit at this point may lead to limited exposure (too medial), or violate the weight-bearing cartilage on the tibial plafond (too lateral). Concerns of the technique include the difficulty of reduction and potential for malunion because apposition may not be colinear with respect to the osteotomy cut.[296,390] An incongruent joint surface after fixation could possibly lead to secondary osteoarthritis of the ankle joint.[143,296]

In order to obtain a congruent joint surface after fixation, the osteotomy cut is best directed perpendicularly to the articular surface of the tibia (Figure 2). An osteotomy that is too vertical or too horizontal may result in an incongruent joint surface (i.e., step off) or shortening of the medial malleolus after fixation (Figure 3). Furthermore, the fixation screws should be directed perpendicularly to the osteotomy plane (Figures 2 and 4).

The longitudinal tibial axis can serve as an intraoperative reference to direct the medial

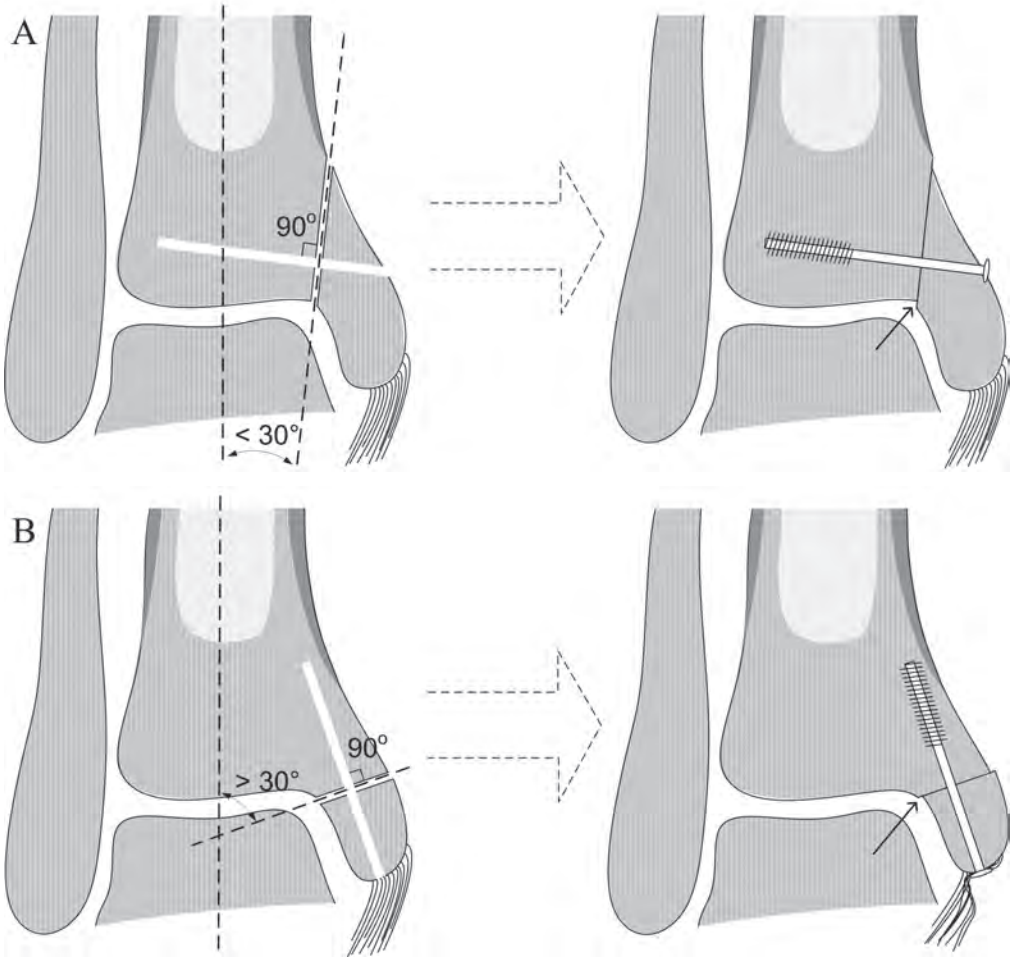


Figure 3. Schematic drawings of wrong techniques in which the osteotomy angle is too vertical (A) or too horizontal (B), resulting in a step off at the articular surface (small arrows).

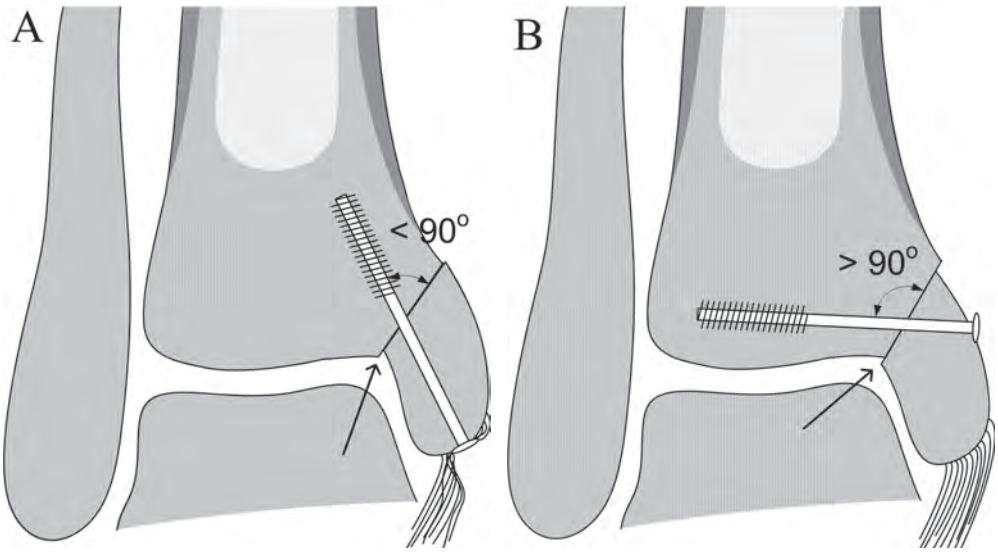


Figure 4. Schematic drawing showing the importance of the direction of fixation screws. The screws should be placed perpendicularly to the osteotomy (see figure 2). Even when the osteotomy is performed correctly, a rather vertical (A) or horizontal (B) insertion of the screws may result in an incongruent joint surface after reduction (arrows). Vertical screw placement also causes disruption of the deltoid ligament (A).

malleolar osteotomy. This axis is commonly used for several orthopaedic procedures, including total knee arthroplasty and high tibial osteotomy.[29,194,369]

The objectives of this study were to determine (1) the direction of the oblique medial malleolar osteotomy perpendicular to the articular surface in relation to the longitudinal tibial axis, (2) the interindividual variation in a group of patients, and (3) the reliability of the radiographic methods used.

Materials and methods

To determine the optimal direction of the osteotomy, we assessed ankle radiographs and computed tomography (CT) scans. Using radiography, we measured the intersection (i.e., angle between the tibial plafond and medial malleolar articular facet), and assessed the tibial axis as a reference to the osteotomy direction. Because the intersection resembles a curved cylinder rather than a 2-dimensional corner, CT was used as a reference standard to compare with radiography and to assess its intra-articular course.

Patients

We assessed 46 ankle radiographs and CT scans of 45 consecutive patients (one bilateral) with an osteochondral talar lesion who had visited the outpatient department of our institution from 2006 to 2008. According to Walter and associates, a sample size of 40 was able to detect a minimally acceptable level of reliability of 0.6 and a hoped-for reliability of 0.8, with $\alpha = 0.05$ and a power of 80%.[443] The patients were derived from two ongoing prospective clinical studies on osteochondral lesions of the talus for which approval of the local Medical Ethics Committee was obtained [unpublished]. None of the patients had a history of tibial or ankle fracture. The mean age was 34 ± 12 years. There were 30 men and 15 women. Twenty-five

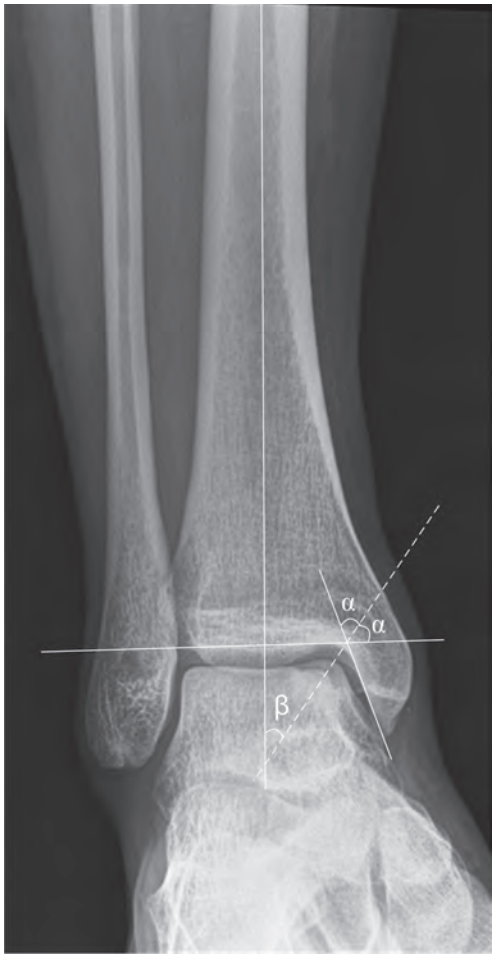


Figure 5. Anteroposterior mortise radiograph of a right ankle showing the intersection angle (αα) between the tibial plafond and medial malleolus. The bisector of this angle (dashed line) indicates the optimal medial malleolar osteotomy, which is perpendicular to the articular surface. The angle (β) between the osteotomy and the longitudinal tibial axis was assessed as a reference to the osteotomy.

lesions were located in the right ankle and 21 in the left. The medial talar dome was affected in 34 ankles, the lateral in eight, the central in two, and both the medial and lateral in two.

Radiography

Digital weight-bearing anteroposterior mortise view radiographs included the foot distally and approximately half of the lower leg proximally (Figure 5). The radiographs (4.0 mAs; 57 kV) were made with the patients' legs in 15° of internal rotation and the knees extended, with the X-ray beam positioned approximately 1 m from the ankle and directed horizontally, as previously described.[240,440]

To determine the optimal osteotomy cut, we measured the intersection angle (αα), defined by tangential lines of the tibial plafond and of the medial malleolar articular facet (see figure 5), using a Picture Archiving and Communication System (PACS, GE Healthcare, Chicago, IL). The bisector of this angle (α), indicating the osteotomy relative to the tibial plafond, was graphically reconstructed. The tibial axis was defined by the line connecting two points in the middle of the proximal and distal tibia.[266] The angle (β) between the osteotomy and the longitudinal axis of the tibia was measured (see figure 5).

All radiographic angles were measured by two independent observers to analyze interobserver reliability. One observer measured the angles a second time in a different order 1 month after the first series to determine intraobserver reliability.

Computed tomography

Additionally, we assessed 46 multislice helical CT scans of the same ankles in plantigrade position that included the tibial plafond and talus. Axial CT scans were obtained with an increment of 0.3 mm and a thickness of 0.6 mm, and 1-mm coronal slices were reconstructed (Philips MX8000 spiral CT system, Philips Medical Systems, Eindhoven, the Netherlands).

To determine the intra-articular course of the intersection, both observers measured the intersection angle (αα) on the most anterior and the most posterior coronal reconstructions of the tibial plafond, as well as on the middle

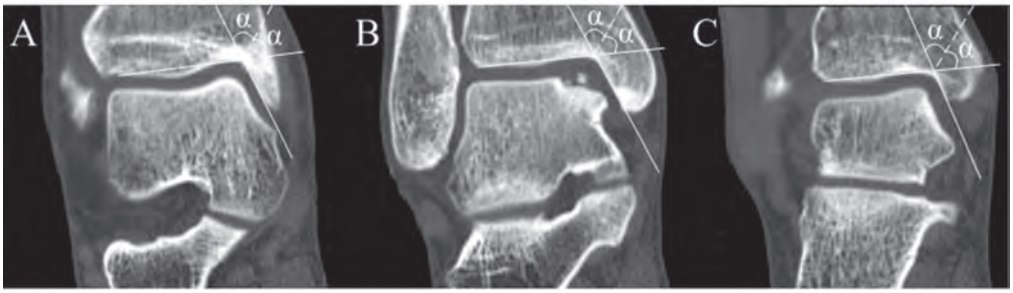


Figure 6. Coronal computed tomography scans of the same patient as in figure 5 showing the most anterior (A), middle (B), and most posterior (C) intersection (αα).

portion of the tibial plafond, using PACS (Figure 6). As with the radiographs, the intersection was defined by tangential lines of the tibial plafond and medial malleolar articular facet. The mean of the anterior, middle, and posterior intersection angles was calculated to compare with the radiographic measurements. The bisector of this angle indicated the osteotomy relative to the tibial plafond.

Statistical analysis

The values of the angles are presented as mean ± standard deviation of both observers' first measurement for each measurement made.[51] Intraclass correlation coefficients (ICC) were calculated to determine intraobserver and interobserver reliability. According to Fleiss, the reliability is considered good if the ICC is 0.40 – 0.75 and excellent if the ICC is more than 0.75.[134] Paired t-tests were performed to assess the systematic difference of sequential measurements as well as the systematic difference between corresponding angles on radiography and CT. Agreement between radiography and CT was assessed by generating a Bland and Altman plot.[51] We considered an osteotomy angle that differed less than 5.0° between radiography and CT as clinically acceptable. Because repeated measurements on the same subject will vary around the true value, measurement error (s_w) of each parameter (i.e., within-subject standard deviation) was calculated as described by Bland and Altman.[52] Statistics were performed in SPSS version 16.0 (SPSS, Chicago, IL). A p-value less than 0.05 was considered significant.

Results

The results of radiographic measurements are presented in table 1. The intersection angle (αα) between the tibial plafond and the articular surface of the medial malleolus was measured 114.5° ± 6.3°. The osteotomy (α) relative to the tibial plafond (i.e., the bisector of this angle) was 57.2° ± 3.2°. The direction of the proposed osteotomy (β) relative to the tibial axis was measured 30.4° ± 3.7° (Figure 7). Forty (87%) of 46 ankles were measured within 5.0° (i.e., 25.4° - 35.4°) of the mean value.

The intraobserver reliability of radiographic measurements was excellent (ICC, 0.90 – 0.93; p <0.001). Accordingly, the interobserver reliability was good to excellent (ICC, 0.73 – 0.82; p <0.001). The systematic difference between both measurements of one observer ranged from 0.5° (95% confidence interval [CI], 0.0° – 1.0°) for the osteotomy (α) relative to the tibial plafond to 1.0° (95% CI, 0.0° 1.9°) for the intersection (αα). There was no systematic difference between observers for the osteotomy relative to

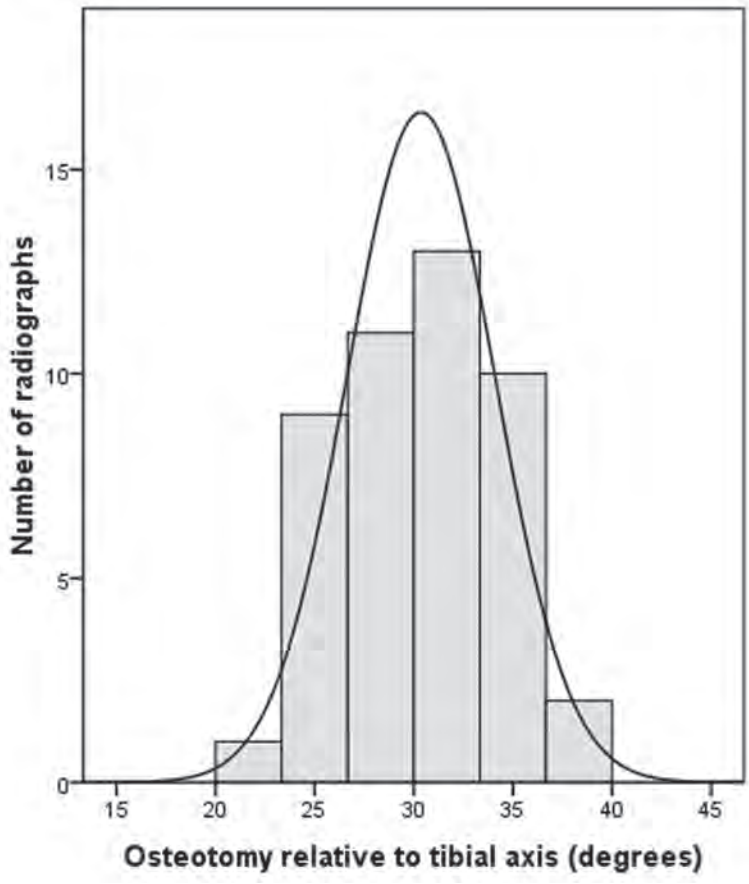


Figure 7. Histogram representing the distribution of the measured osteotomy relative to the tibial axis. The normal curve indicates a normal distribution with little dispersion (standard deviation, 3.7°) around a mean of 30°.

the tibial axis (mean, 0.0°; 95% CI, - 0.8° - 0.9°). The intraobserver measurement error ranged from 1.2° (osteotomy relative to tibial axis) to 2.4° (intersection), and the interobserver measurement error ranged from 1.4° to 2.9° (Table 1).

The intersection angle as measured on CT from anterior to posterior ranged from 109.8° ± 7.8° at the middle portion of the tibia to 117.3° ± 5.4° at the anterior tibia (Table 2). The mean of the anterior, middle, and posterior intersection angles between the tibial plafond and the articular surface of the medial malleolus was 113.0° ± 5.5°, corresponding to an osteotomy of 56.5° ± 2.8° relative to the tibial plafond.

Interobserver reliability of CT was good to excellent (ICC, 0.65 – 0.91; p <0.001). The systematic difference was highest for the posterior intersection (mean, 2.1°; 95% CI, 0.0° - 4.2°). The measurement error ranged from 1.2 (osteotomy relative to tibial plafond) to 5.2 (posterior intersection).

There was no statistically significant systematic difference between radiographic and CT measurements of the mean intersection (mean, 1.4°; 95% CI, -0.4° – 3.2°) or the osteotomy (mean, 0.7°; 95% CI, -0.2 – 1.6) relative to the tibial plafond. The limits of agreement (i.e., mean ± 2 × standard deviation of the difference

Table 1. Results of radiographic measurements

					Intraobserver reliability			Interobserver reliability		
Angle	Observer 1 (°)	Observer 2 (first measurement) (°)	Observer 2 (second measurement) (°)	Mean[a] ± SD (°)	ICC	Difference (mean, 95% CI)	S_w	ICC	Difference (mean, 95% CI)	S_w
Intersection	113.8 ± 6.1	115.1 ± 7.1	116.0 ± 7.3	114.5 ± 6.3	0.90	1.0 (0.0 – 1.9)	2.4	0.82	1.3 (0.1 – 2.4)	2.9
Osteotomy ∠ tibial plafond	56.9 ± 3.0	57.6 ± 3.6	58.0 ± 3.6	57.2 ± 3.2	0.90	0.5 (0.0 – 1.0)	1.2	0.82	0.6 (0.1 – 1.2)	1.4
Osteotomy ∠ tibial axis	30.4 ± 3.4	30.3 ± 4.5	29.9 ± 4.5	30.4 ± 3.7	0.93	0.6 (0.1 – 1.0)	1.2	0.73	0.0 (-0.8 –0.9)	2.1

The intersection was defined as the angle between tangential lines of the tibial plafond and the articular facet of the medial malleolus. The osteotomy relative to the tibial plafond was defined as the bisector of the intersection angle. All ICCs were statistically significant with p-values <0.001.
[a] Mean of both observers' first measurement. ICC = intraclass correlation coefficient, SD = standard deviation, S_w = measurement error, and 95% CI = 95% confidence interval.

Table 2. Results of CT measurements

				Interobserver reliability		
Angle	Observer 1 (°)	Observer 2 (°)	Mean ± SD (°)	ICC	Difference (mean, 95% CI)	S_w
Anterior intersection	116.4 ± 5.5	118.2 ± 5.8	117.3 ± 5.4	0.81	1.8 (1.0 – 2.7)	2.5
Middle intersection	109.8 ± 7.8	109.8 ± 8.2	109.8 ± 7.8	0.91	0.1 (-1.0 – 1.1)	2.5
Posterior intersection	110.9 ± 9.5	113.0 ± 7.6	112.0 ± 7.8	0.65	2.1 (0.0 – 4.2)	5.2
Mean intersection	112.4 ± 5.4	113.7 ± 6.0	113.0 ± 5.5	0.84	1.3 (0.4 – 2.2)	2.3
Osteotomy ∠ tibial plafond	56.2 ± 2.7	56.9 ± 3.0	56.5 ± 2.8	0.84	0.7 (0.2 – 1.1)	1.2

The mean intersection according to CT was calculated as the mean of the anterior, middle, and posterior intersections. The osteotomy relative to the tibial plafond was defined as the bisector of the mean intersection angle.
ICC = intraclass correlation coefficient, SD = standard deviation, S_w = measurement error, and 95%

between radiography and CT) of the osteotomy relative to the tibial plafond were -5.0° to 5.1°. In 45 of 46 ankles the difference was less than 5.0° (Figure 8).

Discussion

In symptomatic osteochondral defects of the talus, surgical treatment is indicated when non-operative treatment has failed.[393] The choice for open versus arthroscopic surgery depends on the location and size of the defect as well as the type of treatment.[296] The preferred technique for primary lesions smaller than 15 mm is debridement and bone marrow stimulation by means of arthroscopy.[432] For secondary and larger lesions there are various treatment options, including autologous cancellous bone grafting, osteochondral autograft transfer (OATS), autologous chondrocyte implantation (ACI), screw fixation, biodegradable double-layer implants, metal implants, and allografts.[408] If the lesion is located on the medial side of the talar dome (63% of cases),[322] most of these treatment options require a medial malleolar osteotomy in order to obtain access to the talar dome.[296]

The purposes of this study were to determine the direction of the oblique medial malleolar osteotomy relative to the long tibial axis, the interindividual variation, and reliability of the radiographic methods used. The direction

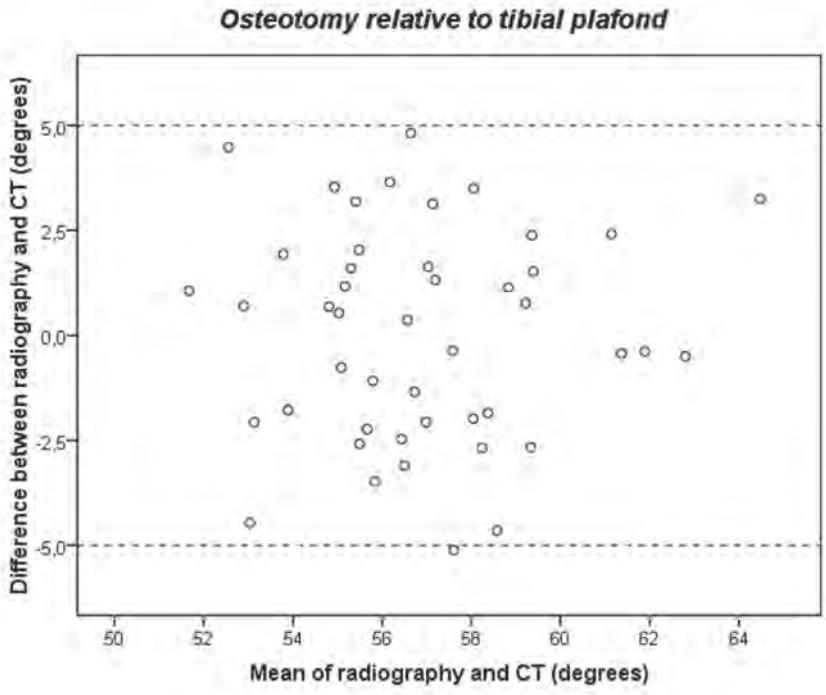


Figure 8. Bland and Altman plot[51] showing the difference against mean for the osteotomy direction relative to the tibial plafond as measured on radiographs and CT scans. The clinically acceptable difference between radiography and CT was defined at 5.0° (dashed lines). Only one measurement was outside this limit.

of the osteotomy was shown to be 30° ± 4° relative to the long tibial axis. This axis is determined intraoperatively by the center of the knee (i.e., tibial tuberosity) proximally and the center of the ankle (i.e., middle of both malleoli) distally. Applying the osteotomy direction of 30° should minimize the occurrence of a step off of the articular surface after reduction. Radiographic and CT measurements were reliable, and indicated that the interindividual variation was small in the studied patient group. Since there was little dispersion (see figure 7), the average 30° angle may be applicable to a larger group of patients. However, if required, the precise osteotomy can be determined reliably for each individual patient according to the methodology described.

The direction of the oblique medial malleolar osteotomy is addressed in few publications. Several authors suggested a direction of approximately 45° to the tibial plafond,[143,281,350] which is more horizontal than the direction found in the present study. Others reported a direction ranging from horizontal[325] to almost vertical.[303]. However, none of these directions are based on measurements, and operative methods to achieve the reported angles were not described.

In addition to the direction and location of the osteotomy, the placement of the fixation screws is important. The lag screws are ideally inserted perpendicularly to the osteotomy cut to achieve optimal compression and a congruent joint surface (see figure 2).[281,366] This

corresponds to a 60° angle relative to the long tibial axis. If the screws are inserted either more horizontally or more vertically, an intra-articular step off might result (see figure 4). The optimal screw direction is thus rather horizontal, which has the additional advantage of preserving the deltoid ligament that originates more distally.

Reports on outcome and complications after oblique medial malleolar osteotomy vary. In a series of 30 patients described by Jarde and colleagues, there was no significant difference in outcome between patients treated through a medial malleolar osteotomy, arthrotomy without osteotomy, or arthroscopy.[200] Likewise, Bazaz and Ferkel reported no osteotomy complications in nine patients.[40] Conversely, Gaulrapp et al. found that a medial malleolar osteotomy frequently led to local osteoarthritis and less favorable clinical findings than arthrotomy without osteotomy.[143] Osteoarthritic changes were seen in more than 50% of 22 patients within 5 years after treatment.[143] Baltzer and Arnold reported malunion in one of 20 cases.[31] In their series, a slight reduction in plantar flexion capacity remained after performing a medial malleolar osteotomy, while the range of motion after using an anterior arthrotomy (23 patients) became equal to the contralateral ankle joint.[31] Unfortunately, it is not possible to relate these outcomes to the direction of the osteotomy used, as the direction was only reported by Gaulrapp et al. who applied 45°.

Although there are different osteotomy techniques of the medial malleolus (see figure 1), each has disadvantages. A transverse approach[325] is relatively straight forward but exposure of the talar dome may be insufficient because it is covered by the contours of the tibial plafond. Accordingly, with the inverted V and inverted U osteotomies, visualization of the talar dome may be inadequate, and they are contraindicated in patients who have large lesions, limited range of motion, or narrow ankle joints.[302,309] A crescentic osteotomy has the advantage of conforming to the contour of the talar dome but is made in a horizontal direction, which restricts perpendicular access to the talar dome.[442] A step-cut osteotomy, introduced in 1991 and modified in 2008,[13,243] provides excellent access but perpendicular fixation of the distal fragment at the articular surface is difficult because the osteotomy enters the joint vertically while the screws are inserted obliquely.[255] The oblique osteotomy is therefore our technique of choice.

There are some limitations of the present study. The measurements utilized a method that relied on 2-dimensional measurements of a 3-dimensional structure. Comparing the intersection angle at the anterior, middle, and posterior portion of the tibia as measured using CT, the biggest difference was found between the anterior and the middle portions (mean, 7.5°; see table 2). This difference corresponds to a difference in osteotomy direction of 3.8°. Hence, the osteotomy is ideally created in different directions from anteriorly to posteriorly. However, it would be difficult to reproducibly create the osteotomy in this manner because the oscillating saw blade and osteotome are straight. Hence, a straight osteotomy is made in clinical practice. The mean of the anterior, middle, and posterior osteotomy is therefore the best alternative, and this angle corresponded well to the osteotomy determined by radiography. Another limitation is the absence of intraobserver reliability of CT. The radiographic measurements were repeated by an observer but the CT measurements were not. We considered the radiographic measurements the most important because these provide a clinical guideline, while the CT measurements were made to verify the radiographically measured intersection angle and determine the course of the intersection. Advantages of radiography are the availability, the low costs and the depiction of approximately half of the tibia, allowing assessment of the tibial axis,

which makes it specifically useful for preoperative planning. Although the proximal tibia was not completely visible, the results of our study and those of another study indicate that the described methodology for assessing the tibial axis is reliable (Table 1).[266] However, it remains unknown whether this radiographic tibial axis perfectly corresponds to the intraoperative tibial axis, and if the proposed radiographic osteotomy direction corresponds to the clinical direction. We currently perform the osteotomy routinely in the described direction by using the tibial axis as a reference. Clinical studies are indicated to assess whether this angle results in congruent fixation and prevents secondary osteoarthritis.

Conclusion

The authors present radiographic measurement techniques to determine preoperatively the optimal oblique medial malleolar osteotomy direction. The average osteotomy should be aimed 30º relative to the tibial axis, in order to exit perpendicularly to the articular surface at the intersection between tibial plafond and articular facet of the medial malleolus.

Chapter 12

Clinical tip: aiming probe for a precise medial malleolar osteotomy

Christiaan J.A. van Bergen
Gabriëlle J.M. Tuijthof
Mikel L. Reilingh
C. Niek van Dijk

Foot & Ankle International
2012;33(9):764-766.

Introduction

Operative exposure of medial osteochondral lesions and fractures of the talus that cannot be treated arthroscopically frequently requires a medial malleolar osteotomy.[296,351,390,461] Various techniques have been described since a transverse osteotomy was introduced in 1947.[13,302,309,325,366,442] The oblique osteotomy has been ascribed several advantages, including excellent exposure of the talus, preservation of the deltoid ligament, and optimal screw compression.[351]

Most surgeons agree that the osteotomy should exit at the intersection between the tibial plafond and the articular facet of the medial malleolus (Figure 1).[40,167,281,350,351,413] The optimal angle has been determined to be 30° in relation to the long tibial axis.[413] If the osteotomy is created too medially (i.e. in the articular facet of the malleolus), exposure of the talar dome may be insufficient for adequate treatment. Furthermore, a small distal fragment may be prone to fracture when fixed at the end of the procedure. Conversely, if the osteotomy is created too laterally, it will exit in the tibial plafond. This is undesirable because the medial tibial plafond directly articulates with the medial talar dome,[286] and damage to this weight-bearing area might lead to secondary osteoarthritis.[143]

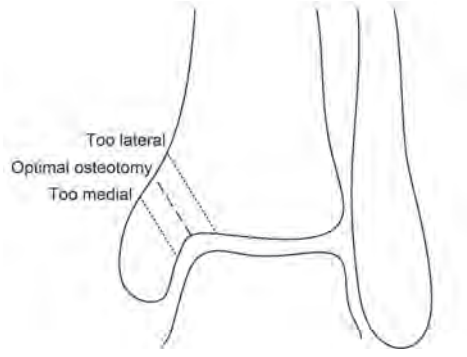


Figure 1. Schematic coronal view of an ankle showing the optimal oblique medial malleolar osteotomy exiting at the intersection between tibial plafond and articular facet of the medial malleolus.

Precise identification of the intersection is important for an accurate osteotomy. Intraoperatively, it is particularly difficult to identify the posterior part of the intersection because of the tight operative working area and the adjacent neurovascular bundle. This report describes the use of a right-angled aiming probe to identify both the posterior and anterior parts of the intersection between the tibial plafond and medial malleolus in order to make a precise osteotomy.

Technique

The patient is placed in the supine position with a tourniquet around the thigh. A rolled-up apron is placed underneath the lateral malleolus to facilitate eversion of the foot and improve exposure of the talus.

A curvilinear skin incision is made over the medial malleolus. The anterior skin is mobilized. Using a periosteal elevator, the surgeon dissects over the anterior medial malleolus and distal tibia. A Hohmann retractor is placed over the distal tibia. Some fatty tissue is removed, and a small anterior arthrotomy exposes the anteromedial talar dome. The level of this anterior superior border of the talar dome will act as a guide to identify the level of the posterior ankle joint.

Next, the tibialis posterior tendon is identified by incising the tendon sheath. A periosteal elevator is used to bluntly dissect over the posterior distal tibia at the level of the ankle joint, approximately 0.5 cm below the anterior joint level. After placement of the Hohmann retractor posterior to the medial malleolus, the posterior capsule of the ankle joint can be visualized and incised.

A right-angled probe (Figure 2) is now used to identify the posterior intersection between the medial malleolus and tibial plafond. The surgeon carefully inserts the tip of the probe

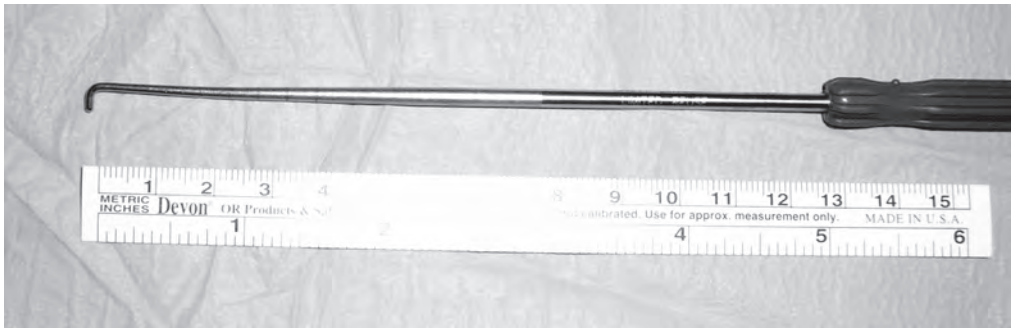


Figure 2. Picture of the right-angled probe. This probe, with a 5-mm tip, is normally used for arthroscopic surgery.

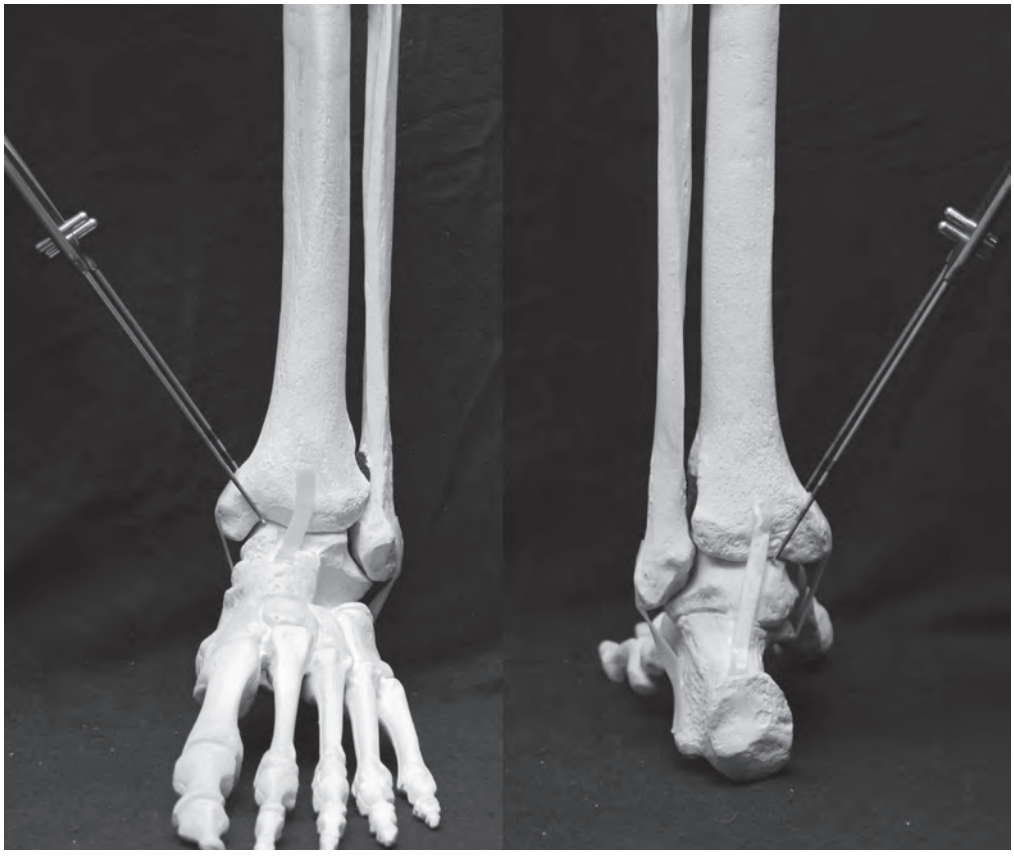


Figure 3. To identify the anterior (left) and posterior (right) intersections between the tibial plafond and medial malleolus, two probes can be inserted simultaneously. They are pulled 30° proximally and medially relative to the long tibial axis.

into the posteromedial joint space by sliding along the posterior aspect of the distal tibia at the intersection with the medial malleolus and gently pulls proximally and medially. The periosteum at the level of the intended osteotomy is marked with a surgical knife, sterile marker

pen, or osteotome. Next, the probe is placed in the anteromedial tibial notch and pulled in a proximal and medial direction, identifying the anterior part of the intersection. The anterior intersection is marked, and this is connected to the posterior intersection as a reference guide to the osteotomy. If available, two probes can be used simultaneously to identify the anterior and posterior intersections (Figures 3 and 4). The probes are best pulled 30° in relation to the longitudinal tibial axis in the coronal plane because this direction is perpendicular to the tibial articular surface at the intersection.[413]

Two Kirschner wires (K-wires), directed perpendicularly to the determined osteotomy plane, are predrilled in the medial malleolus. The screw holes are drilled and tapped, using a cannulated drill, and the K-wires are removed.

The screw holes can be placed either parallel or divergent. If the harvest of cancellous bone is indicated for the treatment of a talar osteochondral lesion or fracture, a divergent direction of the screws allows taking a bone graft of the distal tibia. This can be accomplished by creating a window in the cortex of the tibial metaphysis just proximal to the screw holes and harvesting the cancellous bone using a curette.

An oscillating saw is placed on the incised periosteum and directed at the marked intersection of the tibial plafond and medial malleolus. The osteotomy is created up to approximately 3 to 4 mm above the articular cartilage, while two Hohmann retractors protect the adjacent soft tissue. The osteotomy is completed with the use of an osteotome. This way, the surgeon controls the osteotomy of the articular part and minimizes the risk of damaging the talar cartilage. If desired, an assistant can place an instrument in the joint or manually distract the ankle to protect the talar cartilage.

After the osteotomy has been completed, the surgeon manually retracts and everts the medial malleolus using gauze. Optionally, the distal part is temporarily transfixed by retrograde

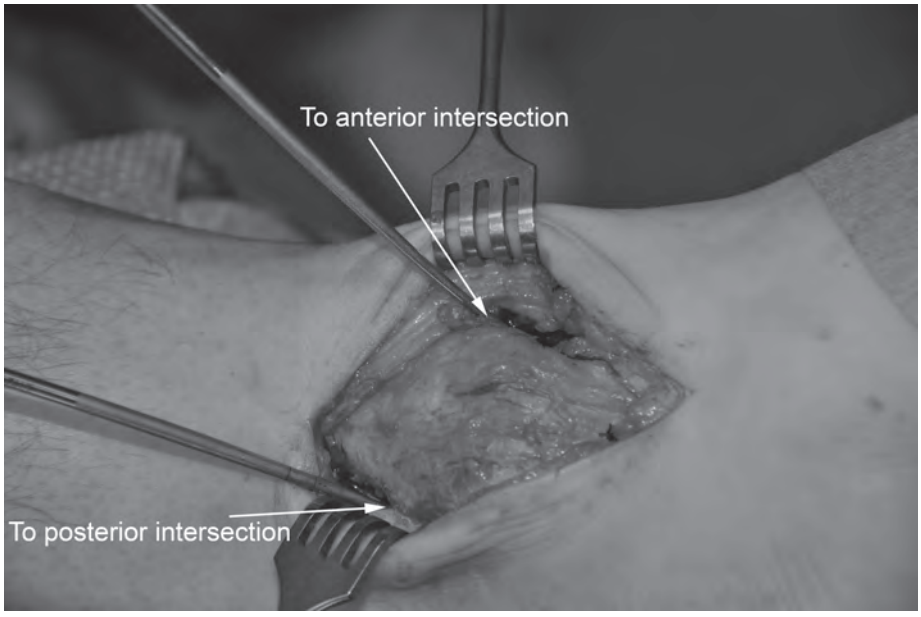


Figure 4. Medial intraoperative view of a left ankle with a probe inserted at each part of the intersection. This figure highlights the limited intraoperative vision of the posterior intersection.

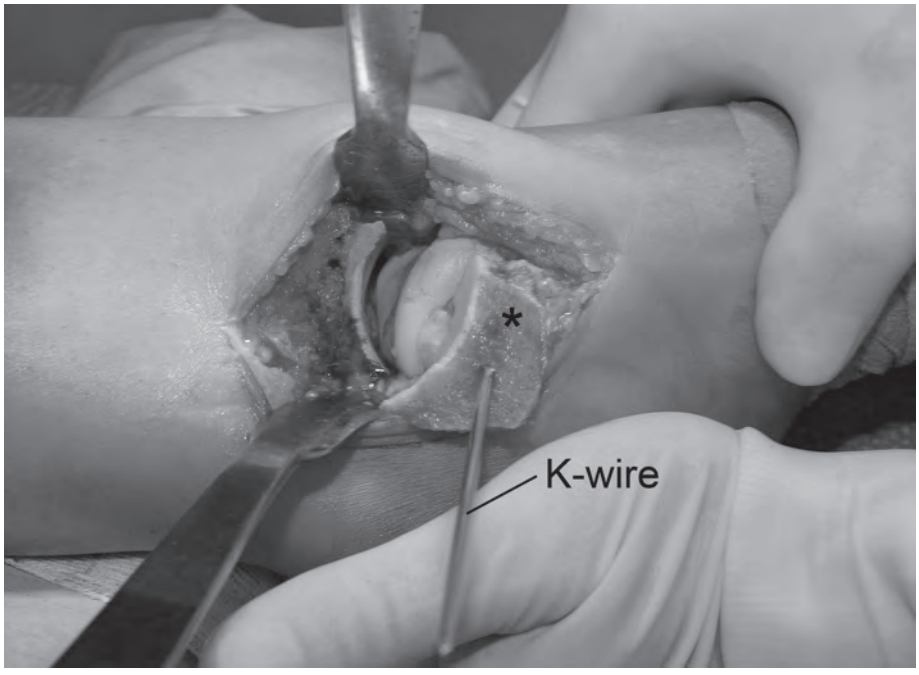


Figure 5. Exposure of the talus through a medial malleolar osteotomy. After the retraction of the medial malleolus (*), a K-wire can be inserted into the talus through one of the predrilled holes to hold the medial malleolus in place.

drilling of a large-diameter K-wire into the talus through one of the predrilled holes. Exposure of the talar dome is improved by forced eversion of the heel. The fibula is hereby used as a fulcrum and the talus is tilted (Figure 5). Care must be taken not to use too much force to prevent fracture of the lateral malleolus.

At the end of the procedure, the medial malleolus is reduced. Initially, large diameter K-wires are placed through the predrilled screw holes to confirm correct alignment. The diameter of the K-wire should correspond to the diameter of the predrilled hole. A Weber bone clamp can be placed for initial compression. Placement of the proximal leg of the Weber clamp is facilitated by creating a small hole in the distal tibial cortex proximal to the osteotomy using a 2.5-mm drill. We routinely use two 3.5-mm cancellous lag screws with a length of 40 or 45 mm. They are inserted into the predrilled screw holes after removal of the K-wires. The bone clamp is released, and the wound is closed.

Discussion

The use of a right-angled probe is described to facilitate identification of the optimal terminal point of the oblique medial malleolar osteotomy (i.e. the intersection between the medial malleolar articular facet and the tibial plafond). Alternatively, intraoperative fluoroscopy can be used to identify the intersection.[308] However, disadvantages of fluoroscopy include exposure to radiation and increasing the operative time. Moreover, it is not easy to identify exactly both anterior and posterior intersection points on a 2-dimensional view. Instead, when using the aiming probe, fluoroscopy becomes unnecessary.

Part IV
Alternative treatment

Chapter 13

Osteochondral defects of the talus: a novel animal model in the goat

Christiaan J.A. van Bergen
Gino M.M.J. Kerkhoffs
Nick Marsidi
Clara M. Korstjens
Vincent Everts
Leo J. van Ruijven
C. Niek van Dijk
Leendert Blankevoort

Tissue Engineering Part C: Methods
2013;19(6):449-457.

Abstract

Osteochondral defects of the talus pose a difficult therapeutic challenge. An experimental animal model of the ankle joint is not available. The aim of this study was to test a newly developed animal model for osteochondral defects of the ankle in vivo. Osteochondral defects were created in the talus of goat hind legs using a posterolateral surgical approach. The defects were filled with either autologous cancellous bone or donor demineralized bone matrix, or left empty as control. After 12 weeks of healing, the specimens were analyzed with radiography, macroscopy, micro-computed tomography, histology, histomorphometry, and fluorescence microscopy. It was possible to create a standardized defect in each talus. The implanted material remained in place. The analyses showed that most bony tissue was generated in the defects filled with autologous bone and least in the control defects. Our findings show that a standard osteochondral defect can be created in the talus by a relatively simple procedure in a large animal that allows qualitative and quantitative evaluation. The model can be used in future experiments to investigate alternative treatment methods before they are introduced into clinical practice.

Introduction

Osteochondral defects of the talus (OCDs) pose a challenging problem to orthopaedic surgeons. Patients with an OCD are typically young adults who experience deep ankle pain on weight bearing, often long after a supination trauma. Nonoperative treatment yields unsatisfactory results in the majority of patients.[458] The primary surgical treatment of most defects is arthroscopic debridement combined with bone marrow stimulation.[458] If results are unsatisfactory – which happens more often in large defects[76,82] – more invasive surgical options are indicated.[408] Current treatment options for these secondary OCDs include autologous cancellous bone grafting, osteochondral autograft transfer and autologous chondrocyte implantation.[408,458] Each of these options has specific disadvantages, for example, an additional operative site with possible donor-site pain, limited availability of material, impaired graft integration, and the necessity of a medial malleolar osteotomy for exposure.[32,147,312] Therefore, experimental studies focus on improvement of these methods and development of alternativ es.[72,138,140,201,252,411,451] However, almost all studies investigate articular defects of the knee, while the ankle joint is rarely investigated.[81] These knee studies cannot reliably be extrapolated to patients with ankle defects, because biomechanical and biochemical properties of the knee and ankle are clearly different.[85,399] The ankle is a congruent joint with thin cartilage that is less susceptible to osteoarthritis than the knee.[181,234]

The use of animal models is often an essential step in the testing of orthopaedic procedures before clinical use in humans.[313] To our knowledge, an animal model for ankle OCDs is not described in the literature. The aim of this study was to test a newly developed caprine model for OCDs of the talus, by evaluating an established treatment (autologous cancellous bone graft), an alternative treatment (demineralized bone matrix [DBM]), and no treatment (control).We defined the following criteria for a successful model: 1) the animal's joint anatomy and body weight are comparable to humans, 2) the surgical technique is reproducible (regarding the operative approach as well as size and location of the OCD), 3) the morbidity of the animals is acceptable (defined as full weight bearing and free of pain within 1 week), 4) the

repair is best after applying an established treatment and minimal in control defects, and 5) the method must be accurate enough to detect small differences between groups.

Materials and methods

Animals, experimental design, and operative technique

The study was approved by the Animal Care and Use Committee of the University of Amsterdam, the Netherlands. Three adult female Dutch milk goats (Capra Hircus Sana) were used with an approximate age of 4 years and a weight of 50, 80, and 89 kg, respectively. All goats were healthy, according to physical examination and blood tests by a veterinarian. They were kept in group housing starting 2 weeks before surgery.

Surgery was performed on both ankles in a sterile fashion with the goat in the lateral decubitus position under general anesthesia with endotracheal intubation. Before anesthesia, intramuscular injections with prophylactic antibiotic (Pen & Strep, Fendigo sa/nv, Brussels, Belgium), ketamine 10 mg/kg (Alfasan International BV, Woerden, the Netherlands) and atropine 1.5 mg (Centrafarm Services BV, Etten-Leur, the Netherlands) were administered. Intravenous etomidate (B.Braun Melsungen AG, Melsungen, Germany) was injected to induce

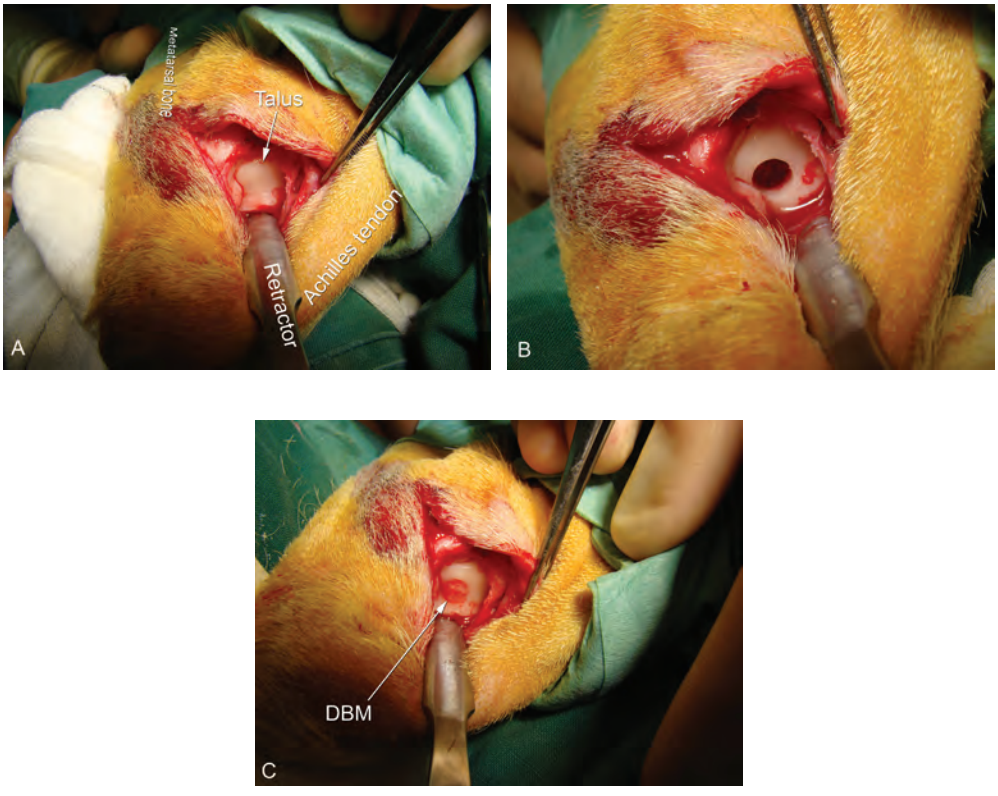


Figure 1. Digital pictures showing key aspects of the surgical technique. The talar dome was exposed through a posterolateral approach (A). A cylindrical defect with a diameter and a depth of 6 mm was created (B) and filled up to the level of the cartilage (C). DBM = demineralized bone matrix.

general anesthesia. Fentanyl 250 µg (Hameln pharmaceuticals gmbh, Hameln, Germany) and midazolam 15 – 20 mg (Dormicum, Roche Nederland BV, Woerden, the Netherlands) were injected intravenously, and repeated, when necessary. Isoflurane 1.0% - 2.5% (Nicholas Piramal Limited, London, UK) was administered by inhalation.

A curvilinear skin incision was made just posterior to the lateral malleolus, parallel to the Achilles tendon (proximal) and the calcaneus (distal). After mobilization of the lateral saphenous vein, an arthrotomy was performed in the plane between the peroneal tendon (anterior) and the lateral saphenous vein (posterior). A Hohmann retractor was placed behind the medial talus to optimize exposure of the talus and protect the tendons and neurovascular structures. Full dorsiflexion of the ankle allowed maximal exposure of the articular surface of the talus (Figure 1A). In the center of the talar trochlea, a custom-made drill socket with a diameter of 6 mm was placed, which ensured drilling to a precise depth of 6 mm. Under continuous cooling with saline, the defect was drilled perpendicularly to the talar surface, starting with a sharp drill and finishing with a milling cutter to achieve a flat base of the defect (Figure 1B). A goat study investigating the natural course of knee defects showed that 6-mm defects do not heal spontaneously within 1 year.[198]

Each defect was treated according to a predefined randomization scheme with autologous cancellous bone (harvested from the iliac crest) or commercially available cortical demineralized bone matrix (Bonus™ DBM, Biomet BV, Dordrecht, the Netherlands) hydrated with normal saline, or left empty (untreated control). Filling up to the level of the articular cartilage surface (Figure 1C) was ensured by inserting ample material press-fit and moving the ankle through a full range of motion (removing any abundant material above the surface of the defect due to the congruency of the ankle joint). The joint capsule and subcutaneous tissue were closed with interrupted 2-0 absorbable sutures, and the skin was closed with absorbable sutures placed in a continuous intracutaneous pattern.

Postoperatively, analgesic medication consisted of a single subcutaneous injection of 0.005 mg/kg buprenorfine (Temgesic®, Schering-Plough BV, Utrecht, the Netherlands), twice daily, as pain demanded (indicated by limping). After wound healing was completed, which took ~1 week, the animals were kept outdoors in a large natural environment with food ad libitum and without activity restrictions. Eating habits, ambulatory activities, and health status were monitored daily.

After 12 weeks, the goats – back in the experimental animal center – were sacrificed by injecting a lethal dose of pentobarbital (Euthasol 20%, ASTfarma BV, Oudewater, the Netherlands) in the jugular vein, after they had been sedated with an intramuscular injection of ketamine 10 mg/kg (Alfasan International BV, Woerden, the Netherlands), xylazine 2 ml (Sedazine®, ASTfarma, Oudewater, the Netherlands) and atropine 1 mg (Centrafarm Services BV, Etten-Leur, the Netherlands).

Analyses

Radiography

Lateral radiographs of the ankles were taken before surgery and directly after surgery. Anteroposterior and lateral radiographs were taken after autopsy.

Macroscopy

The tali were excised directly after terminating the goats, and digital high-resolution photographs were taken of the talar and opposite articular surfaces. Macroscopic grading was

performed by two observers. A general macroscopic articular evaluation system was used that awards 0 to 2 points to each of five categories: range of motion, intra-articular fibrosis, restoration of contour, cartilage erosion, and appearance.[340] Ten points indicate a completely normal appearance, and 0 points indicate a severely damaged joint surface. Furthermore, the talar articular surface was assessed according to the validated International Cartilage Repair Society (ICRS) cartilage repair assessment.[62,420] This score consists of three items (i.e., degree of defect repair, integration to border zone, and macroscopic appearance) that are each assigned a maximum of 4 points, with a total of 12 indicating a normal appearance. The scores of the two observers were averaged and outliers with a difference of more than 1 point were scored again, until consensus was reached.[91]

Micro-computed tomography

The talar heads were sawn off with a water-cooled band saw to optimize penetration of fixative for histological evaluation and allow placement of the tali in the micro-computed tomography (μCT) scanner. Specimens were fixed in 4% phosphate-buffered formaldehyde for 1 week. After they were submerged in 70% ethanol and subjected to a vacuum to remove all the air from the cancellous bone, they were scanned in a μCT scanner (μCT 40, Scanco Medical AG, Brütisellen, Switzerland). With the defects facing down, the specimens were mounted in cylindrical specimen holders and secured with synthetic foam. This setup ensured consistent scanning of the defects parallel to the axis of the scan tube. The resolution of the scans was 18 μm, the voltage 70 kV, the current 114 μA, and the integration time 1000 ms. To discriminate between bone and background, the reconstructions were segmented using an adaptive threshold procedure, which determines the minimum between the two peaks in the gray values histogram, representing bone and background, respectively.[331]

For quantitative analysis, two cylindrical volumes of interest were defined: one representing the complete OCD, measuring 6 mm in diameter and 6 mm in depth, and one representing the central OCD, measuring 3 mm in diameter and 5 mm in depth. The latter volume of interest was defined at 5 mm in depth to avoid analyzing original bone at the base of the OCD. The ratio between bone volume and tissue volume (BV/TV) was determined for all volumes of interest using morphometric software (Scanco Medical AG, Brütisellen, Switzerland).

In addition to the six operated specimens, five unaffected goat tali from a spinal fusion study (unpublished data) were μCT scanned and analyzed in the same manner to obtain normative data.

Histology

After fixation, the specimens were dehydrated using ascending grades of ethanol (70% to 100%) in two steps a week, and embedded in methylmethacrylate (BDH Laboratory Supplies, Poole, England). After cold polymerization, the undecalcified specimens were cut into coronal 5-μm sections with a Jung-K microtome (R. Jung, Heidelberg, Germany). Seventy-five central sections were obtained from each specimen. Every third section (n = 25) was stained with Goldner's trichrome method, giving the following staining pattern: green for mineralized tissue, red for osteoid, blue or black for cell nuclei, and light orange or red for cytoplasm. The Goldner stained sections were used for evaluation of mineralized bone tissue, osteoid, fat cells, osteocytes, osteoblasts, and osteoclasts. Every second out of three sections was stained with toluidine blue for examination of structural details and cell appearance of the articular surface of the defects. Every third out of three sections was

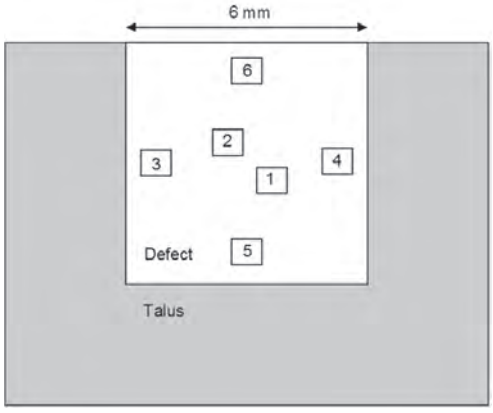


Figure 2. Schematic drawing showing the six measurement fields in which histomorphometry analysis was performed. The fields represent areas in the center (1 – 2), close to the borders (3 – 5), and close to the surface (6) of the defect.

left unstained for fluorescence microscopy. Two observers, blinded to the treatment modality, qualitatively assessed the stained sections using transmitted light microscopy.

Histomorphometry

One representative Goldner-stained mid-section of each talus was analyzed using a Leica DMRA microscope that was connected to Leica Qwin computer software (Leica Microsystems Imaging Solutions, Cambridge, UK). A special routine was written for quantitative measurements of bone parameters.

Three areas of interest were defined: (1) the center of the OCD, (2) close to the borders of the defect (lateral, medial, and bottom), and (3) close to the articular surface of the defect. Six representative measurement fields of 307,000 μm^2 were selected and digitized at a magnification of ×200, resulting in one to three measurement fields for each area of interest (Figure 2). The mineralized bone area (bone%) and osteoid area (osteoid%) were measured. The number of osteocytes, osteoblasts, and osteoclasts was counted at a magnification of ×400. All measurements were performed twice by one observer and once by a second observer, both blinded to treatment allocation. The mean of both observers is reported, and intraobserver and interobserver reliability were calculated.

Fluorescence microscopy

Fluorochrome labels were injected at 3 (oxytetracyclin 20 mg/kg), 6 (calcein green 10 mg/kg), and 9 weeks (alizarin red 25 mg/kg) after surgery. The dosages were based on the recommendations by van Gaalen et al.[435] One unstained section that was adjacent to the Goldner stained section was used for histomorphometry. Six measurement fields (magnification, ×400), similar to the areas of interest of histomorphometry, were digitized using fluorescent filters. According to the manufacturer's guidelines, the D-filter (excitation 355 – 425 nm, emission 470 nm) was best used for oxytetracyclin and alizarin, and the I3-filter (excitation 450 – 490 nm, emission 515 nm) was best used for calcein, although each label was visible with both filters. One independent observer, blinded to treatment allocation, measured the distance between two consecutive lines at ~10 locations within a measurement field. The mineral apposition rate (MAR, μm/day) of the bone was calculated as the average distance between the corresponding edges of two consecutive fluorescent bone labels, divided by the number of days between start and end of the administration period.

Statistical analysis

Individual quantitative results are presented. The treatment pairs were not statistically compared because of the small sample size. Mean and standard deviation (SD) were calculated of the μCT scans of five unaffected goat tali. To assess intra- and interobserver reliability of the

histomorphometric measurements, intraclass correlation coefficients (ICCs) were calculated using SPSS version 18.0 (SPSS, Chicago, IL). ICCs of more than 0.75 are considered excellent.[134]

Results

With the operative technique described, it was possible to create a standardized OCD in the talus. After surgery, the first two animals recovered well without complications. The goats were able to walk on their hind legs within 24 h. The third goat had persistent pain of the right ankle,

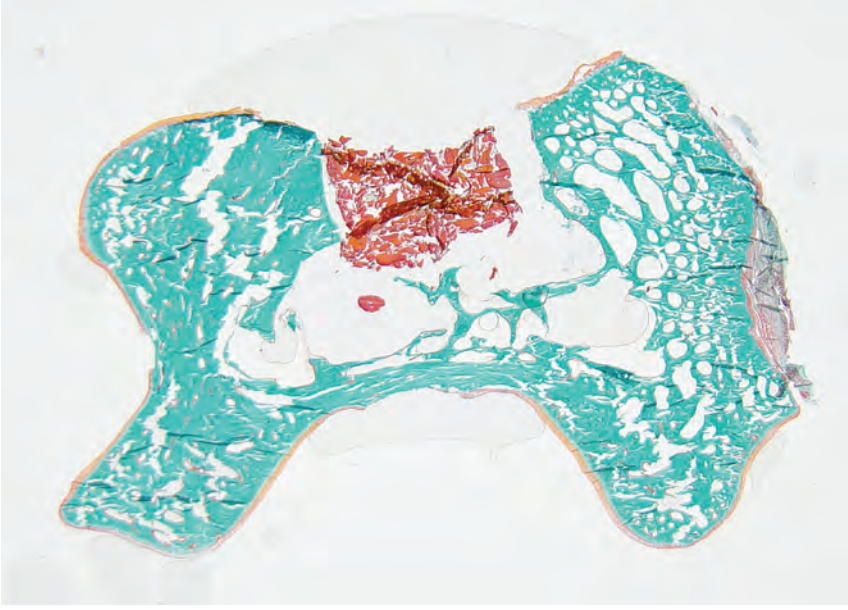


Figure 3. Histological analysis of a defect filled with DBM, 2 weeks after implantation, shows that the material remained in situ.

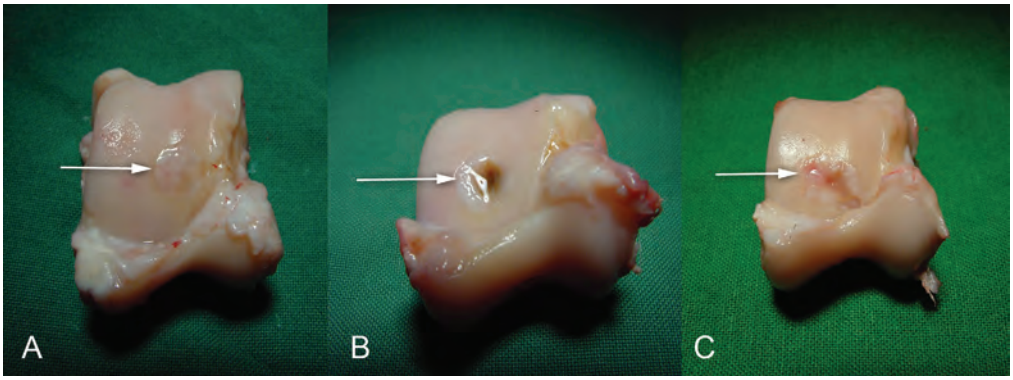


Figure 4. Macroscopic view of three specimens. (A) Autologous bone. (B) DBM. (C) Control. The arrows indicate the osteochondral defects.

despite treatment with subcutaneous analgesics for 2 weeks and intramuscular antibiotics (Pen & Strep, Fendigo sa/nv, Brussels, Belgium) for 1 week. There were no signs of infection. Surgical exploration of the painful ankle after two weeks revealed no pathology. Cultures showed no pathologic micro-organisms. An exact cause could not be determined. The goat was terminated for ethical reasons 2 weeks following initial surgery. Obduction revealed no pathologic conditions. Histology of the right talus showed that the original DBM was still in situ (Figure 3). In consultation with the Animal Care and Use Committee, the sacrificed animal was replaced by another goat, which recovered well from surgery and completed the follow-up period.

Radiography

Preoperative radiographs showed normal ankle joints without signs of osteoarthritis. Immediate postoperative radiographs showed the OCDs in three cases (one of each treatment); the defects were not visible in the other three. On the final radiographs after the 12-week period, none of the defects was visible.

Macroscopy

Macroscopic inspection of the ankle joints revealed no signs of inflammation. All defects were covered with tissue resembling fibrocartilage (Figure 4). The surrounding talar cartilage and opposite joint surfaces appeared completely normal. The highest macroscopic assessment scores were achieved in an autologous bone specimen and the lowest in a DBM specimen (Table 1).

Micro-CT

In the complete 6-mm OCDs, BV/TV ranged from 0.10 to 0.45 (Table 2). In comparison, mean

Table 1. Results of macroscopy

Treatment (goat)	General macroscopic articular evaluation	ICRS
AB (1L)	6	5.5
AB (2R)	9	11.5
DBM (2L)	5	4
DBM (3R)	6	8
Control (1R)	6	6
Control (3L)	6	7.5

AB = autologous bone, DBM = demineralized bone matrix, ICRS = International Cartilage Repair Society cartilage repair assessment,[62] L = left, and R = right.

Table 2. Results of μCT, showing the ratio between bone volume and tissue volume

Treatment (goat)	Complete defect	Central 3-mm cylinder
AB (1L)	0.44	0.29
AB (2R)	0.34	0.22
DBM (2L)	0.1	0.01
DBM (3R)	0.3	0.13
Control (1R)	0.23	0
Control (3L)	0.45	0.04
Unaffected (mean ± standard deviation)	0.68 ± 0.06	0.70 ± 0.05

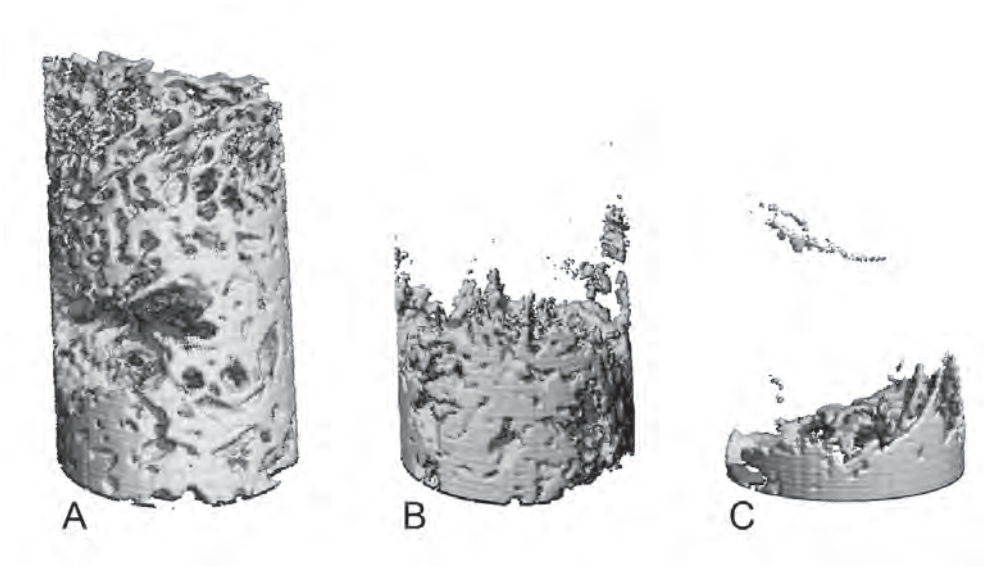


Figure 5. Three-dimensional reconstructions of μCT scans. These volumes of interest represent central 3×5-mm cylinders. (A) Autologous bone. (B) DBM. (C) Control.

BV/TV of the five unaffected tali was 0.68 (SD, 0.06) in the complete cylinder and 0.70 (SD, 0.05) in the central 3-mm cylinder. The 3-mm central cylinders can be considered indicative for the regenerative capacity of the treatment applied because bone had regenerated from the borders and bottoms of the defects. In these 3-mm cylinders, the tali treated with autologous bone showed the most bone tissue, and the control group the least (Figure 5).

Histology

In the OCDs treated with autologous bone, diffuse bone formation and near-complete filling was observed (Figure 6A). There was continuing bone remodeling, as indicated by large areas of osteoid tissue and the presence of abundant osteoblasts and a rare osteoclast. At the articular surface, the defect was mainly composed of (mineralizing) fibrocartilage tissue with some chondrocytes embedded. Underneath the surface there were areas of woven and lamellar bone.

In the defects treated with DBM, some bone formation was observed – both lamellar and woven – with abundant osteoid in one specimen (Figure 6B). Most bone was formed at the borders but also some in the center of the defects. The original DBM was not visible. In one specimen the surface of the defect was composed of a thick layer of fibrocartilage. In the other, the surface was mainly composed of connective tissue, fibroblasts, and leukocytes (lymphocytes and granulocytes).

The control defects did not heal (Figure 6C). Some woven bone originated from the borders of the defects. Occasional mineralization of cartilaginous tissue at the surface suggested endochondral ossification. The greatest part of the defects was filled with fat cells and connective tissue.

Histomorphometry

Histomorphometry followed the same pattern as the μCT analysis (Table 3). Most bone formation was observed in the autologous bone pair; most

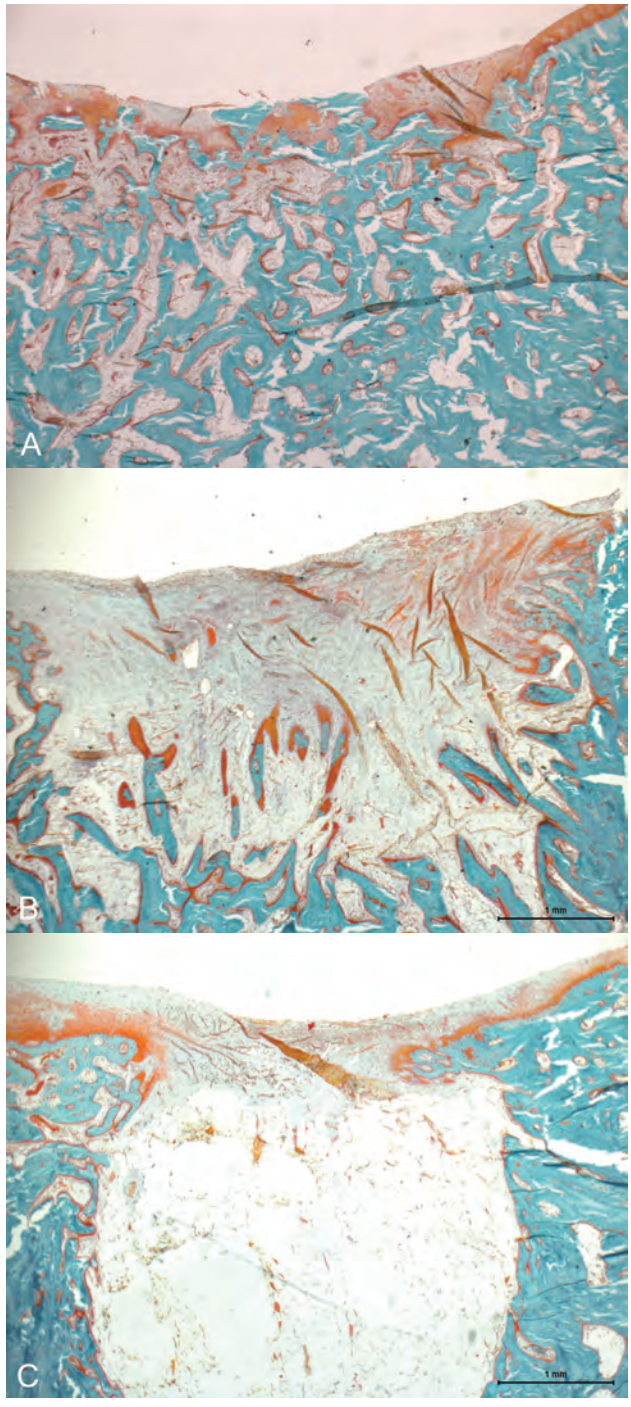


Figure 6. Histologic sections with Goldner's trichome staining; magnification, ×25. (A) Autologous bone. (B) DBM. (C) Control. Scale bar = 1 mm.

osteoid formation was found in DBM. There was only one specimen (autologous bone) with bony and osteoid tissue in the measurement field of the surface. Osteoclasts were rarely found: only a single osteoclast was seen in one measurement field (center) in one specimen (autologous bone).

The intra- and interobserver reliability of the histomorphometric measurements were excellent; the lowest ICC was 0.80 (interobserver reliability of osteoblasts in the center; p = 0.016), and the highest was 1.00 (intra- and interobserver reliability of bone% in all areas of interest; p <0.001).

Fluorescence microscopy

MAR varied from 0 μm/d in the areas where no bone growth was observed to 11 μm/d in the center of the defect in an autologous bone specimen (Table 4). The calcein green labels were best visible, followed by oxytetracyclin and alizarin, respectively (Figure 7). The MAR could not be analyzed in two occasions because alizarin red labels could not be detected (see Table 4).

Discussion

A new caprine model was developed for the comparison of treatments for osteochondral ankle lesions. The model is presented in this study and seems feasible for the evaluation of new treatment options. Similar to the human ankle joint, the caprine ankle is congruent and able to bear high loads. The goat's body weight and metabolic and remodeling rates correspond to those of humans.[21] Furthermore, the proportion of cartilage to subchondral bone and the subchondral bone consistency are reportedly close to humans.[81] The operative technique described is reproducible, a standardized OCD can be created in each talus, and the implanted material remains in situ. Most importantly, there

Table 3. Results of histomorphometry

	Bone%			Osteoid%			Osteocytes (no.)			Osteoblasts (no.)		
Treatment (goat)	Center	Borders	Surface	Center	Borders	Surface	Center	Borders	Surface	Center	Borders	Surface
AB (1L)	62.1	67.8	19.8	3.2	1.4	0.2	16	24	4	15	11	0
AB (2R)	16.7	38.2	0.0	1.7	3.1	0.0	4	17	0	3	9	0
DBM (2L)	5.0	15.3	0.0	0.2	1.2	0.0	0	11	0	0	6	0
DBM (3R)	26.0	35.7	0.0	9.8	9.8	0.0	4	16	0	8	21	0
Control (1R)	0.4	14.8	0.0	2.8	5.1	0.0	1	3	0	0	4	0
Control (3L)	0.0	83.7	0.0	0.0	1.0	0.0	0	30	0	0	0	0

Table 4. Results of fluorescence microscopy (mineral apposition rate, μm/d)

	Week 3-6			Week 6-9		
Treatment (goat)	Center	Borders	Surface	Center	Borders	Surface
AB (1L)	6.1	2.8	2.7	8.3	5	No label
AB (2R)	11.0	5.7	0.0	6.4	9	0.0
DBM (2L)	6.4	7.1	0.0	No label	6.5	0.0
DBM (3R)	0.0	3.7	0.0	0.0	6.7	0.0
Control (1R)	0.0	5.6	0.0	0.0	5.8	0.0
Control (3L)	0.0	5.9	0.0	0.0	4.7	0.0

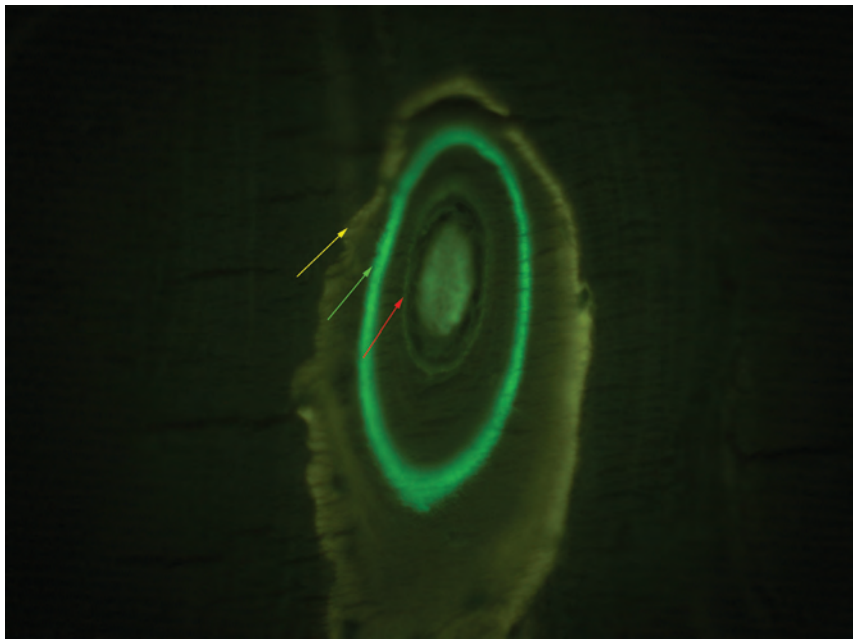


Figure 7. Fluorescence microscopy with I3 filter (excitation 450 – 490 nm, emission 515 nm), magnication ×400. Fluorochrome labels were injected at 3 (oxytetracyclin; yellow arrow), 6 (calcein; green arrow), and 9 weeks (alizarin; red arrow) to analyze the mineral apposition rate. Calcein was best visible, followed by oxytetracyclin and alizarin, respectively.

is a clear difference in outcome between defects treated with autologous cancellous bone and control defects. This was particularly shown by the quantitative analyses with μCT and histomorphometry. The mean BV/TV of the central OCDs was 0.25 in the autologous bone pair, 0.07 in the DBM pair, and 0.02 in the control pair (see Table 2). Similarly, mean central bone% according to histomorphometry was 39.4 in the autologous bone pair, 15.5 in the DBM pair, and 0.2 in the control pair (see Table 3). However, no definite conclusions can be drawn on the effectiveness of the treatment because of the low number of animals studied.

Previous animal studies have been performed predominantly on the stifle joint.[8,81] These studies may be inadequate for assessing treatment modalities for ankle OCDs, as there are some specific differences between the knee and ankle. First, physiological cartilage properties differ. Congruent joints, such as the ankle, have a thin layer of cartilage to distribute the load and maintain an acceptable level of stress, whereas incongruent joints, such as the knee, have thicker areas of cartilage to increase the contact area between joint surfaces.[354] The cartilage of the ankle has a greater compressive modulus compared with the knee.[354,399] Second, the knee and ankle joints seem to respond differently to cartilage injury. There appears to be a net anabolic response to injury in the ankle cartilage and a net catabolic response in the knee.[26,181,311] Ankle cartilage may be more resistant to osteoarthritis development for a number of reasons, including higher equilibrium and compressive moduli, better intercellular communications, increased resistance to inflammatory molecules, increased

metabolic activity, and higher congruency of the articular surfaces.[116,181] Because of these differences, an animal model specifically developed for the ankle joint is required.

Although most animal models are designed for unilateral surgery,[8] a bilateral defect was created in the present model. This method reduces the number of animals needed and allows for paired treatment comparison. A paired analysis may be a better strategy than unilateral evaluation or random assignment of treatment in bilateral models, since the regenerative capacities may differ from animal to animal (see Tables 2 and 3).

Clinically, plain radiographs are obtained for the initial diagnosis of OCD and for follow-up. However, in the present animal model, radiographic evaluation as an outcome measure proved to be useless because the defects were not visible in most instances. In contrast, histomorphometry is traditionally used to measure bone formation and is considered the gold standard.[258] It is common practice to analyze representative areas of interest to approximate the total defect.[21,238,338] Disadvantages of this method are a possible modification of the structure of the tissue by slice preparation and the long time required for all processing steps.[151,258] MicroCT provides a fast and nondestructive technique to characterize and measure the 3-dimensional geometric and density properties of a bone specimen.[202] Gielkens et al. compared the intraobserver reliability of μCT and histomorphometry.[151] They concluded that both analyses are reliable but are used preferably in combination.

Fluorescence microscopy is a useful supplement to plain histology to detect the speed of regeneration during the follow-up period.[435] When using fluorescence microscopy, there is no need to sacrifice additional animals at a shorter follow-up period. The success of fluorochrome detection depends on various aspects, for example, the type, concentration, route of administration and methods of visualization.[435] In the present study, the recommendations of van Gaalen et al. were used.[435] Unfortunately, the alizarin red labels were not always visible, without an obvious cause. In contrast, calcein green was clearly visible in all cases. No adverse events related to the injections of the fluorochrome labels were seen in this study.

The follow-up period was 12 weeks. Revascularization and conversion of a bone graft into a vital trabecular structure have been reported to occur at approximately 3 months in the goat, which corresponds to 8 months in humans.[238] However, the regeneration process was ongoing, observed by large areas of osteoid tissue and the presence of abundant osteoblasts. The final situation may thus not be achieved after 12 weeks. In studies with multiple follow-up periods, no substantial regeneration of OCDs in the knee joint was observed after 24 weeks, suggesting that a follow-up period of 24 weeks may show the final outcome.[72,138]

The principal limitation of the present study is the limited number of animals used. In consultation with the Animal Care and Use Committee, only three animals were studied because the morbidity of the animals could not be anticipated, as this was the first time the ankle model was used. Out of the initial six ankles, one showed persistent pain. This goat was sacrificed, and the substitute goat recovered uneventfully. Thus, one out of eight ankles had inacceptable morbidity. This morbidity corresponds to that of other goat studies investigating cartilage repair.[92,340,342] We therefore believe that following studies with the presented model are justified. Because of the small number of animals and the variability in reparative capacity of the goats, we cannot reliably draw conclusions on the investigated repair procedures. Larger studies with paired analyses are indicated.

Conclusions

The caprine model described in the current study seems suitable for the study of osteochondral ankle defect treatment in vivo. The operative technique is fairly simple and allows the creation of a standardized OCD for qualitative and quantitative evaluation. The goat model can be used in future experiments investigating alternative treatment methods for this challenging condition before introduction into clinical practice.

Acknowledgments

The authors would like to thank Mr. K.W. Meijer, Mr. G. Vink, and Mr. P. Sinnige for taking care of the animals. Mrs. J. Hogervorst is acknowledged for support with preparation of the histology sections. Biomet BV, Dordrecht, the Netherlands, is gratefully acknowledged for financial support and supply of the DBM.

Chapter 14

Demineralized bone matrix and platelet-rich plasma do not improve healing of osteochondral defects of the talus: an experimental goat study

Christiaan J.A. van Bergen
Gino M.M.J. Kerkhoffs
Murat Özdemir
Clara M. Korstjens
Vincent Everts
Leo J. van Ruijven
C. Niek van Dijk
Leendert Blankevoort

Osteoarthritis and Cartilage
2013;21(11):1746-1754.

Abstract

Objective

The purpose of this study was to evaluate the effectiveness of demineralized bone matrix (DBM) with and without platelet-rich plasma (PRP) in the treatment of osteochondral defects (OCDs) of the talus. We hypothesized that treatment with DBM would result in more bone formation than no treatment in control OCDs, and that PRP would further enhance the regenerative capacity of DBM.

Method

A standardized 6-mm OCD was created in each talus of 16 adult goats. According to a randomization scheme, one OCD of each goat was treated with allogeneic DBM hydrated with normal saline (n = 8) or hydrated with autologous PRP (n = 8). The contralateral OCD (n = 16) served as control. After 24 weeks, the animals were euthanized and the tali excised. Various outcome parameters were analyzed with use of macroscopic evaluation, micro-computed tomography, histology, histomorphometry, and fluorescence microscopy.

Results

None of the analyses revealed statistically significant differences between the groups for any of the parameters analyzed in any volume of interest. For example, the mean bone volume fraction of the defect, as measured by micro-computed tomography, was 0.56 (95% confidence interval [CI], 0.44 – 0.68) for DBM hydrated with normal saline and 0.52 (95% CI, 0.40 – 0.65) for DBM hydrated with PRP, compared to 0.53 (95% CI, 0.45 – 0.61) and 0.54 (95% CI, 0.44 – 0.64) for the internal controls, respectively (p >0.05).

Conclusion

In contrast to our hypotheses, no beneficial treatment effect of DBM with or without PRP was found for OCDs of the caprine talus.

Introduction

In the treatment of talar osteochondral defects (OCDs), repair of the subchondral bone is an important aim of the procedure.[160] The presence of subchondral bone is essential for survival of chondrocytes.[16] The affected subchondral bone is thought to cause the pain.[434] Restoration of the subchondral bone may improve the weight-bearing capacity of the ankle and prevent further cyst formation.[434]

Urist pioneered the use of demineralized bone matrix (DBM) for bone defects.[405,419] Since his work, there has been increasing experience with DBM in both animals[123,140,272,405] and humans.[145,283] The sequence of events after implantation of DBM mirrors that of endochondral ossification.[405] Bone morphogenetic proteins

(BMP-2, -4, and -7) seem to be responsible for the formation of bone and possibly cartilage that are induced by DBM.[318,406] The BMPs present in DBM attract mesenchymal stem cells through chemotaxis and act as morphogens that may direct the differentiation of these cells into an osteochondrogenic lineage. Different fluids can be used for rehydration of the DBM before application, including normal saline, bone marrow aspirate, antibiotics solution, whole blood, or platelet concentrate.

Platelet-rich plasma (PRP) is a promising biomaterial that contains concentrated growth factors, including transforming growth factor-β (TGF-β) and platelet-derived growth factor (PDGF).[14,195] TGF-β in PRP may stimulate chemotaxis and mitogenesis of osteoblast and chondroblast precursors and inhibit osteoclast formation and bone resorption.[225,275] PDGF may promote mitogenesis, angiogenesis, and chondrocyte proliferation.[10,225,275] Although, in theory, PRP may enhance the biologic activity of DBM, the combination of DBM and PRP has had contradictory results.[213,275,324]

The purpose of the present study was to evaluate the effectiveness of DBM with or without PRP in the treatment of ankle OCDs in goats. We hypothesized that (1) treatment with DBM would repair more bone than control OCDs, and that (2) PRP would further enhance the regenerative capacity of DBM.

Materials and methods

Animals and experimental design

The study was approved by the Animal Care and Use Committee of the University of Amsterdam. A caprine model was used, specifically designed for ankle OCDs.[417] Sixteen adult female Dutch milk goats (Capra Hircus Sana) were included with an approximate age of 4 years. All goats were healthy, according to physical examination and blood tests performed by a veterinarian. The goats were weighed on a digital scale before surgery and at final follow-up. Surgery was performed in a sterile manner on both ankles, with the goat under general anesthesia with endotracheal intubation. A single intramuscular dose with prophylactic antibiotics (Pen & Strep, Fendigo sa/nv, Brussels, Belgium) was injected preoperatively. The ankle joint was exposed through a posteromedial approach. Normal articular surfaces were confirmed by visual inspection. Standard OCDs of 6 mm in diameter and depth were created with specially developed instruments.[417] According to a predefined randomization scheme, one defect of each goat was treated with DBM hydrated either with normal saline (0.9% NaCl solution) ("DBM treatment"; n = 8) or with PRP ("DBM+PRP treatment"; n = 8), and the other served as a control ("DBM control" or "DBM+PRP control"). In each case, the material was inserted press-fit up to the level of the adjacent cartilage surface. The joint capsule and skin were closed in a standard fashion.[417]

During recovery, the animals were kept outdoors in a large natural environment, without activity restrictions, and with food ad libitum. Eating habits, ambulatory activities, and health status were monitored daily.

Since previous studies showed no substantial change in repair of knee OCDs after 24 weeks,[72,138] the goats were euthanized 24 weeks after surgery by injecting a lethal intravenous dose of pentobarbital. All analyses were performed by observers blinded to the treatment provided.

Demineralized bone matrix

Commercially available cortical DBM (Bonus™ DBM, Biomet BV, the Netherlands) was used. This DBM was obtained from human donors

from qualified tissue banks that were registered with the FDA and accredited by the American Association of Tissue Banks. It was granulated, demineralized with organic solvents, freeze-dried (i.e., lyophilized) and processed aseptically. This process resulted in calcium levels of less than 0.1%.[318] It was combined with a collagen-derived carrier (gelatin) from the same donor, packaged in a rehydration syringe, and sterilized by gamma irradiation.

Platelet-rich plasma

Autologous PRP was used for rehydration of the DBM. After induction of anesthesia and before surgery, 27 ml venous goat blood was aspirated into a 30-ml syringe that contained 3 ml of anti-coagulant citrate dextrose A. PRP was isolated by centrifugation at 3200 rpm for 15 min using the gravitational platelet system II (GPS II, Biomet BV, the Netherlands). This preparation system produces 3 ml of PRP with a reported eightfold increase in platelet concentration and a fourfold to sevenfold increase in growth factor concentration compared with whole blood.[120,173,454] The concentration of platelets in the PRP of each subject in the present study was measured using an automated hematology analyzer (XE-5000, Sysmex, Japan) after 5 min of resuspension on a rocker, as recommended by Woodell-May et al.[454] The median platelet concentration of the PRP was 1511 × 10^9/l (range, 82 – 2090 × 10^9/l).

Macroscopy

After the goats were euthanized, the tali were excised and digital high-resolution photographs were taken of the talar articular surfaces. Two independent observers macroscopically graded the photographs with use of the validated International Cartilage Repair Society (ICRS) cartilage repair assessment.[62,420] This score ranges from 0 to 12 points and is subdivided into degree of defect repair, integration to border zone, and macroscopic appearance (4 points each), with a score of 12 indicating a completely normal appearance. The scores of the two observers were averaged, and outliers with a difference of more than 1 point were scored by consensus.[91]

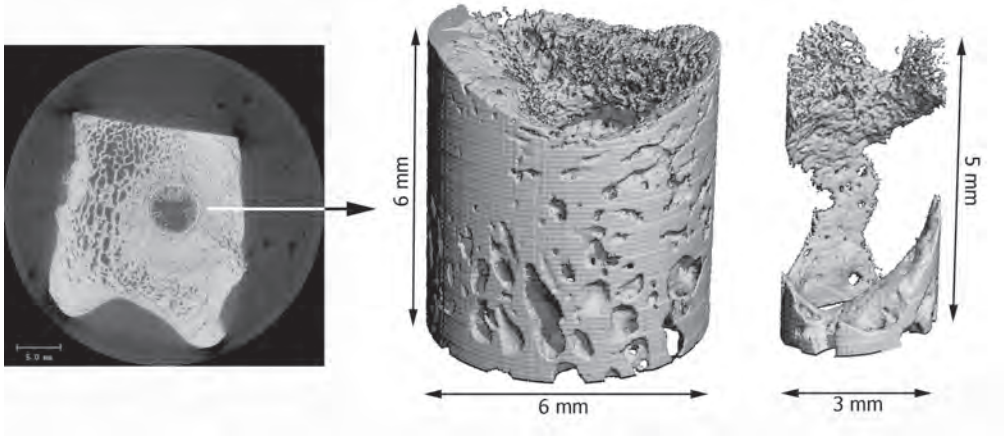


Figure 1. Micro-CT analysis. Transverse cross-section of the talus *(left)* and the two cylindrical volumes of interest representing the complete defect *(middle)* and the central 3×5 mm *(right)*.

Micro-computed tomography

The anterior part of the talus, at safe distance from the OCD, was sawn off with a water-cooled band saw to reduce the size of the specimen, allowing it to be placed in the micro-computed tomography (μCT) scanner, and to optimize penetration of fixative into the specimen. After 1 week in fixative (4% phosphate-buffered formaldehyde), the specimens were submerged in 70% ethanol and temporarily subjected to a vacuum. In the 70% ethanol solution, they were placed in a μCT scanner (μCT 40, Scanco Medical AG, Bassersdorf, Switzerland) and scanned with a resolution of 18 μm. To minimize the noise in the reconstructions, an integration time of 1000 ms was used.

Micro-CT reconstructions were segmented with a threshold level of 467 mg HA/cm^3. Two 3-dimensional cylindrical volumes of interest were defined: one representing the complete OCD (6 mm in diameter and depth), and one representing the central OCD (3 mm in diameter and 5 mm in depth) (Figure 1). Using morphometric software (Scanco Medical AG, Bassersdorf, Switzerland), the following parameters were analyzed: bone volume fraction (bone volume [BV]/tissue volume [TV]), tissue mineral density (TMD) of BV and of TV, and trabecular number, thickness, and separation. The bone volume fraction was the primary outcome of the study.

Histology

After fixation, the specimens were dehydrated using ascending grades of alcohol and embedded in methyl-methacrylate. After cold polymerization, the undecalcified specimens were cut into 5-μm sections with a Jung-K microtome (R. Jung, Heidelberg, Germany). Thirty central sections were obtained of each specimen to overcome sampling error. Every third section was stained with Goldner's trichrome method or toluidine blue for light microscopy, or left unstained for fluorescence microscopy. Two observers simultaneously assessed the stained sections and identified the type of healing.

Histomorphometry

A representative Goldner-stained mid-section of each talus was analyzed using a Leica DMRA microscope that was connected to Leica Qwin computer software (Leica Microsystems Imaging Solutions, Cambridge, UK) with a custom-made routine for quantitative measurements of bone parameters. Two observers simultaneously made the choice for the representative section, based on technical quality and overall appearance. Three areas of interest were defined: (1) the center of the OCD, (2) sides and bottom of the defect (close to the lateral, medial, and deep borders), and (3) the surface (close to the articular surface of the defect).[417] For each area of interest, one (surface), two (center) or three (sides and bottom) representative measurement fields of 3.07×10^5 μm^2 were digitized at a magnification of ×200. Mineralized bone surface area (bone%) and osteoid surface area (osteoid%) were assessed. The numbers of osteocytes, osteoblasts, and osteoclasts were counted at a magnification of ×400 and expressed per area of mineralized bone tissue. These histomorphometric measurements have been shown excellent intraobserver and interobserver reliability.[417]

Fluorescence microscopy

Fluorochrome labels were administered at week 1 (Oxytetracyclin yellow, 32 mg/kg intramuscularly) and weeks 6, 12, 18, and 23 (Calcein green, 20 mg/kg subcutaneously). Fluorescence microscopy was used with fluorescence filters and unstained sections to analyze the speed of bone regeneration (mineral apposition rate

[MAR]). Six measurement fields (magnification, ×400) were digitized, similar to the areas of interest of histomorphometry. The distance between two consecutive fluorescent bone labels was measured at approximately 10 locations within a measurement field by an independent observer blinded to treatment allocation. The MAR (μm/day) was calculated as the average distance divided by the number of days between two injections.

Statistical analysis

The sample size was calculated before the start of the study and was based on the primary outcome BV/TV. Prior data from a pilot study indicated that the standard deviation of BV/TV in the central 3 mm of the OCDs treated with DBM was 0.086.[417] With an intended difference in the mean BV/TV of matched pairs of 0.10, a sample size of eight ankle pairs was able to reject the null hypothesis that the response difference was zero with probability (power) 0.80. The Type I error probability associated with this test of this null hypothesis was 0.05. Because two pairs of treatment were investigated, the total sample size was 16 goats.

Statistical analyses were performed with use of SPSS software (version 18.0; Chicago, Illinois). Variables with normal distribution are reported as mean and 95% confidence intervals (CIs). Data with skewed distribution are reported as median and range. The Wilcoxon signed-rank test was used to calculate p-values of matched pairs (DBM vs. control and DBM+PRP vs. control). The Mann-Whitney U test was used to compare the treatment effect of DBM (i.e., difference of DBM and internal control) with the treatment effect of DBM+PRP (i.e., difference of DBM+PRP and internal control). MARs of different administration periods were compared using the Wilcoxon signed-rank test.

The results were considered statistically significant if the p-value was less than 0.05 for the primary outcome (i.e., BV/TV). To correct for multiple testing, Holm's method was

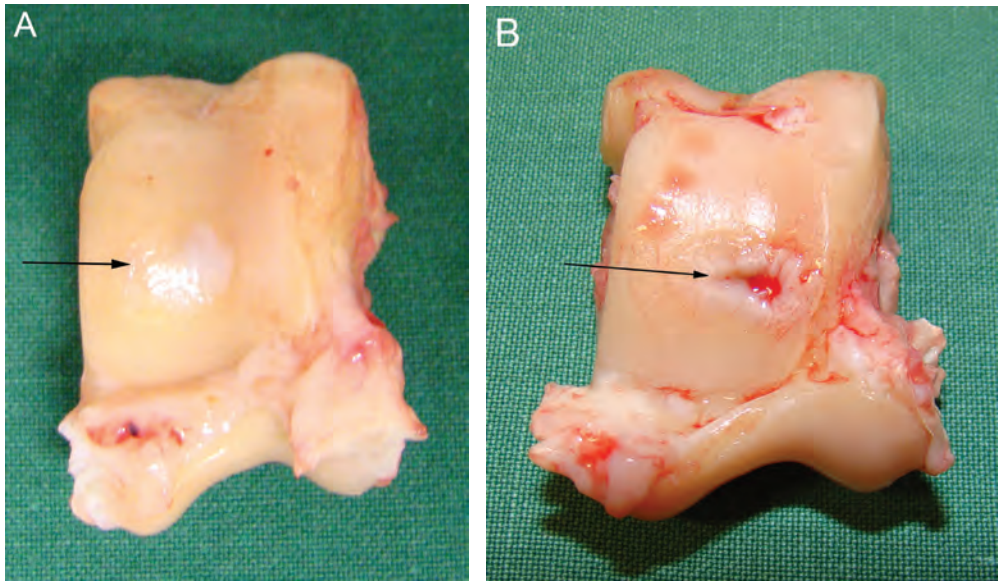


Figure 2. Examples of the best (A; ICRS cartilage repair assessment, 10) and worst (B; ICRS cartilage repair assessment, 3.5) macroscopic appearance of the osteochondral defects (arrows) after 24 weeks of healing. Both are control specimens.

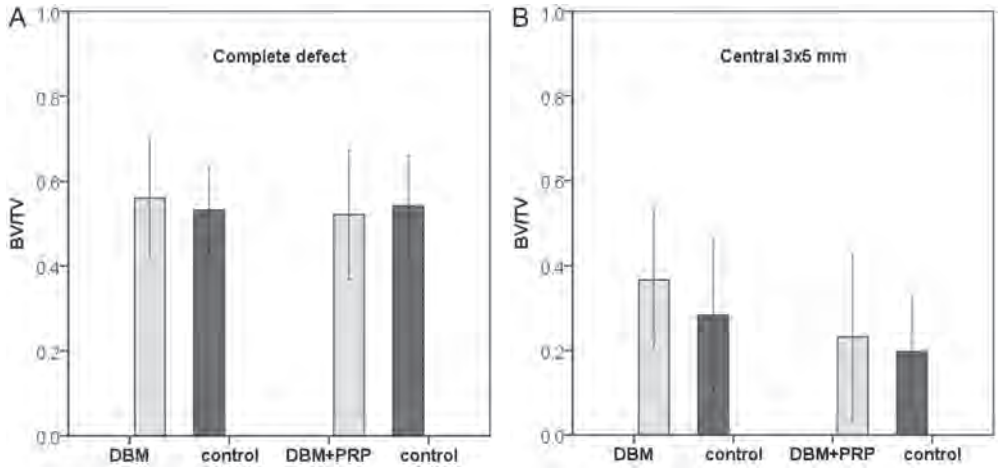


Figure 3. Bar chart showing the mean and 95% confidence interval of the bone volume fraction (BV/TV), according to μCT analysis, of (A) the complete defect and (B) the central 3×5 mm. The differences were not statistically significant ($p > 0.05$).

used for the secondary outcome parameters (macroscopy, histology, histomorphometry, and fluorescence microscopy).[9,186] Because four secondary outcome measures were used, adjusted p-values with significance levels of 0.01 (i.e., 0.05/4) and higher were appropriate.

Results

General results

The surgical procedures and functional recovery were uneventful in 15 goats. After 24 h, no signs of limping or abnormal motion were observed. In one goat, there was a technical failure of the instruments, resulting in an OCD drilled completely through the talus. In consultation with the Animal Care and Use Committee, this animal was terminated and replaced by another, which had no complications. The mean body weight was 73.5 kg (95% CI, 67.1 – 79.8 kg) before surgery and 69.3 kg (95% CI, 63.7 – 75.0 kg) at 24 weeks follow-up.

Macroscopy

All OCDs were macroscopically covered with fibrocartilaginous tissue. The mean ICRS cartilage repair assessment was 8.0 (95% CI, 7.3 – 8.7) for DBM treatment, 8.4 (95% CI, 7.4 – 9.5) for DBM control, 6.9 (95% CI, 5.3 – 8.6) for DBM+PRP treatment, and 7.4 (95% CI, 6.0 – 8.9) for DBM+PRP control (differences not statistically significant) (Figure 2). The surrounding talar cartilage and opposite joint surfaces appeared unaffected.

Micro-CT

There were no significant differences between groups on the primary outcome measure BV/TV or any of the other μCT parameters in either volume of interest (Figure 3 and Table 1). In the DBM+PRP treatment group, there were no statistically significant differences between goats with high concentrations of PRP and those with low concentrations. For example, BV/TV in the complete OCDs of the four goats with the highest PRP concentrations was 0.49 (95% CI, 0.39

Table 1. Outcome of μCT

Treatment group		Complete defect						Central 3x5-mm cylinder					
		BV/TV	TMD of BV (mg HA/cm^3)	TMD of TV (mg HA/cm^3)	Tb.N (mm^{-1})	Tb.Th (mm)	Tb.Sp (mm)	BV/TV	TMD of BV (mg HA/cm^3)	TMD of TV (mg HA/cm^3)	Tb.N (mm^{-1})	Tb.Th (mm)	Tb.Sp (mm)
DBM	Treatment	0.56 (0.44 - 0.68)	709 (682 - 735)	454 (373 - 536)	1.9 (1.4 - 2.4)	0.46 (0.35 - 0.57)	1.1 (0.7 - 1.5)	0.37 (0.23 - 0.50)	680 (653 - 707)	333 (240 - 426)	1.4 (1.0 - 1.9)	0.33 (0.25 - 0.42)	1.2 (0.9 - 1.5)
	Control	0.53 (0.45 - 0.61)	700 (680 - 721)	431 (377 - 486)	2.0 (1.3 - 2.6)	0.41 (0.32 - 0.49)	1.2 (0.7 - 1.6)	0.28 (0.14 - 0.43)	661 (633 - 689)	276 (180 - 373)	1.7 (0.7 - 2.7)	0.26 (0.18 - 0.34)	1.2 (0.7 - 1.8)
DBM+ PRP	Treatment	0.52 (0.40 - 0.65)	695 (681 - 710)	429 (348 - 509)	1.6 (0.9 - 2.3)	0.45 (0.34 - 0.55)	1.6 (0.8 - 2.4)	0.23 (0.07 - 0.39)	657 (632 - 682)	244 (129 - 358)	4.2 (0.0 - 8.4)	0.24 (0.13 - 0.34)	1.1 (0.5 - 1.6)
	Control	0.54 (0.44 - 0.64)	684 (666 - 701)	432 (380 - 485)	1.8 (1.1 - 2.5)	0.37 (0.30 - 0.43)	1.3 (0.9 - 1.7)	0.20 (0.09 - 0.31)	650 (639 - 662)	221 (150 - 292)	0.9 (0.4 - 1.4)	0.23 (0.19 - 0.26)	1.8 (1.3 - 2.3)

The values are presented as the mean, with the 95% confidence interval in parentheses.
There were no statistically significant differences between the groups.
BV = bone volume, Tb.N = trabecular number, Tb.Sp = trabecular separation, Tb.Th = trabecular thickness, TMD = tissue mineral density, and TV = tissue volume.

– 0.58), compared to 0.55 (95% CI, 0.30 – 0.80) in the four goats with the lowest PRP concentrations (p = 1.00).

Histology

Four types of healing patterns were recognized (Figure 4). Type 1 was almost completely healed (>75% repair). In type 2, the subchondral bone was (almost) restored but a cystic lesion underneath the restored bone remained. Type 3 was characterized by regeneration from the margins and bottoms of the defects but a superficial defect remained (25% - 75% repair). In type 4, no or only minimal healing was observed (<25% repair); the original defects were filled with fatty and connective tissue, and the surface was covered with a thin layer of cells. There was high variation in healing patterns between animals (Figure 5), while the left and right tali within a single animal showed more consistency. There were remnants of DBM in two cases: one DBM treatment and one DBM+PRP treatment. Additionally, macrophages were observed in five defects: one DBM treatment, one DBM control, and three DBM+PRP control. Osteoclasts were not found.

Histomorphometry

There were no statistically significant differences in histomorphometry between the groups for any of the parameters analyzed in any of the areas of interest (Table 2).

Fluorescence microscopy

There were no statistically significant differences between the groups (Table 3). Some data were missing due to either no bone or no detectable label in the measurement field, especially in the fourth administration period (week 18 – 23). The MAR of the second administration period (week 6 – 12) of each group was significantly higher than that of the first administration period (week 1 – 6). The MAR did not change significantly in subsequent periods.

Discussion

This study aimed to evaluate the effectiveness of DBM and PRP in the treatment of ankle OCDs in goats. A previously established goat model was utilized, enabling evaluation of treatment of a standard OCD of the talus in a large animal with qualitative and quantitative analyses.[417] The control OCDs in this study can be regarded as bone marrow stimulation of the defect without additional filling.

In contrast to our hypotheses, DBM did not result in improved repair compared to the control defects, nor did PRP enhance the regenerative capacity of DBM. There were no statistically significant differences between the groups on the primary outcome BV/TV, as measured by μCT, or the secondary outcomes, as measured by macroscopy, histology, histomorphometry, and fluorescence microscopy. However, some generalization uncertainty remains because of the dispersion of the outcome data, as demonstrated by the width of the 95% CIs (see Figure 3 and Tables 1 and 3). There were no observations of abnormal motion or limping after 24 h. Although a significantly higher MAR was shown after the first 6 weeks, this finding was similar in each treatment group (see Table 3).

Gao et al. investigated the effect of allogeneic rabbit demineralized cortical and trabecular bone matrix for the treatment of 3-mm OCDs in 10 young rabbit medial femoral condyles.[140] At 6 and 12 weeks postoperatively, the defects were repaired up to 95% of their depth but there was a clear difference between cortical and trabecular DBM. In most of the specimens

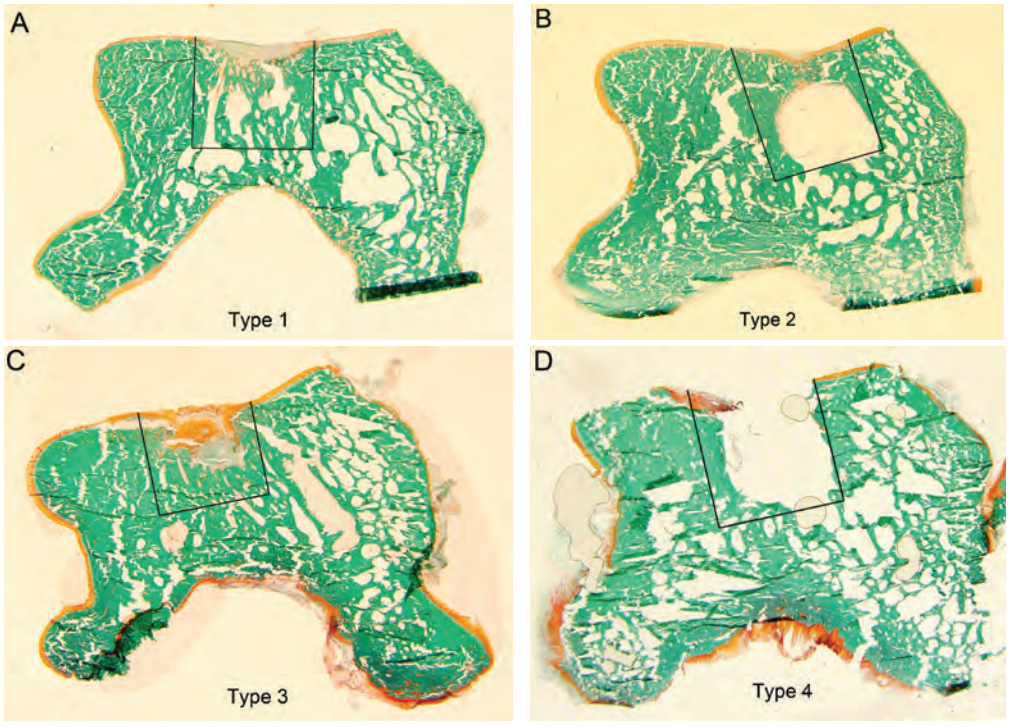


Figure 4. Goldner-stained sections showing four types of healing. Type 1 (A) was almost completely healed. In type 2 (B) , the subchondral bone was (almost) restored but a cystic lesion underneath the restored bone remained. Type 3 (C) was characterized by regeneration from the margins and bottoms of the defects but a superficial defect remained. In type 4 (D), no or only minimal healing was observed. The original defects are indicated with black lines. Subtle differences in size of the defects may be due to slice preparation.

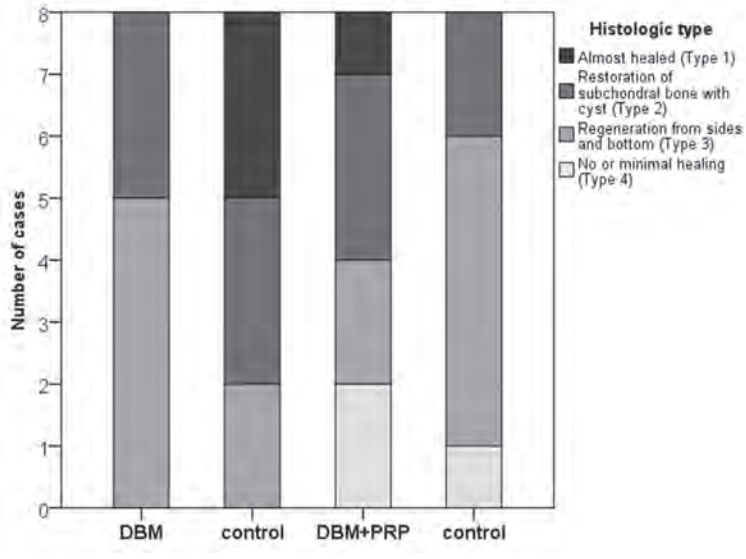


Figure 5. Distribution of histologic healing types.

Table 2. Outcome of histomorphometry

Treatment group		Bone%			Osteoid%			N.Oc ($\times 10^{-4}/\mu m^2$)			N.Ob ($\times 10^{-4}/\mu m^2$)		
		Center	Sides and bottom	Surface	Center	Sides and bottom	Surface	Center	Sides and bottom	Surface	Center	Sides and bottom	Surface
DBM	Treatment	7.7 (0.0 - 64.3)	55.1 (25.7 - 75.1)	0.0 (0.0 - 65.5)	0.1 (0.0 - 2.6)	1.1 (0.4 - 1.6)	0.0 (0.0 - 8.1)	3.1 (0.0 - 8.0)	6.4 (4.0 - 7.9)	0.0 (0.0 - 12.8)	0.0 (0.0 - 9.0)	2.7 (1.3 - 8.5)	0.0 (0.0 - 9.4)
	Control	33.8 (0.0 - 74.9)	58.8 (22.6 - 68.9)	5.5 (0.0 - 71.5)	0.1 (0.0 - 1.6)	1.3 (0.0 - 2.9)	0.0 (0.0 - 7.6)	4.3 (0.0 - 8.3)	6.8 (3.8 - 10.1)	2.3 (0.0 - 24.8)	0.2 (0.0 - 4.0)	2.9 (0.0 - 16.0)	0.9 (0.0 - 3.6)
DBM+ PRP	Treatment	0.0 (0.0 - 64.7)	44.8 (29.5 - 83.6)	9.0 (0.0 - 52.1)	0.0 (0.0 - 1.4)	0.8 (0.1 - 3.3)	0.1 (0.0 - 10.7)	0.0 (0.0 - 8.5)	6.1 (1.7 - 8.9)	2.9 (0.0 - 14.1)	0.0 (0.0 - 7.0)	3.7 (0.0 - 9.1)	2.4 (0.0 - 14.9)
	Control	2.6 (0.0 - 56.5)	58.0 (26.4 - 87.2)	0.0 (0.0 - 31.2)	0.1 (0.0 - 3.9)	0.9 (0.2 - 2.7)	0.0 (0.0 - 13.5)	1.3 (0.0 - 6.8)	6.2 (5.3 - 9.2)	0.0 (0.0 - 8.4)	1.1 (0.0 - 5.6)	4.2 (0.0 - 17.1)	0.0 (0.0 - 12.1)

The values are presented as the median, with the range in parentheses.
There were no statistically significant differences between the groups.
N.Ob = number of osteoblasts and N.Oc = number of osteocytes.

Table 3. Outcome of fluorescence microscopy

Treatment group		MAR week 1 - 6 (µm/d)			MAR week 6 - 12			MAR week 12 - 18			MAR week 18 - 23		
		Center	Sides and bottom	Surface	Center	Sides and bottom	Surface	Center	Sides and bottom	Surface	Center	Sides and bottom	Surface
DBM	Treatment	0.29 (0.19 - 0.39)	0.35 (0.26 - 0.45)	0.31 (0.20 - 0.42)	1.02 (0.39 - 1.66)	1.02 (0.82 - 1.22)	0.63 (0.52 - 0.74)	1.07 (0.52 - 1.62)	1.16 (0.91 - 1.41)	2.20	1.50 (0.81 - 2.19)	1.09 (0.99 - 1.19)	NA
	Control	0.47 (0.22 - 0.71)	0.51 (0.36 - 0.66)	0.53 (0.36 - 0.68)	1.13 (0.99 - 1.26)	1.09 (0.90 - 1.27)	1.13 (0.63 - 1.63)	1.72 (0.75 - 2.70)	1.31 (1.02 - 1.59)	NA	NA	1.24 (0.93 - 1.55)	NA
DBM+ PRP	Treatment	0.45 (0.14 - 0.75)	0.52 (0.40 - 0.63)	0.36 (0.28 - 0.43)	1.18 (0.83 - 1.54)	1.53 (1.15 - 1.92)	1.01 (0.97 - 1.04)	1.09 (1.01 - 1.17)	1.04 (0.61 - 1.48)	1.43 (0.65 - 2.21)	1.40 (0.83 - 1.97)	1.11	NA
	Control	0.41 (0.25 - 0.56)	0.43 (0.32 - 0.54)	0.31 (0.19 - 0.42)	1.11 (0.95 - 1.27)	1.38 (0.82 - 1.93)	0.95 (0.47 - 1.43)	0.98 (0.71 - 1.25)	1.42 (0.84 - 1.99)	NA	1.46	1.56 (0.63 - 2.50)	NA

The values are presented as the mean, with the 95% confidence interval in parentheses.
The MAR of the second administration period (week 6 – 12) of each group was significantly higher than that of the first administration period (week 1 – 6). The MAR did not change significantly in subsequent periods.
MAR = mineral apposition rate and NA = not applicable.

treated with cortical DBM, the repair tissue was composed of subchondral bone and a top layer of cartilage that was smooth and integrated with the adjacent cartilage. In contrast, trabecular DBM resulted in a fibrillated surface without integration with the adjacent cartilage. Gurevitch et al. studied 1.5-mm OCDs in the intercondylar region of rat knees after implantation of cortical DBM particles.[166] In contrast to Gao et al., the former authors observed no proper healing of the defects after a follow-up of up to 24 weeks. Likewise, Dahlberg and Kreicbergs investigated allogeneic DBM in intercondylar groove OCDs of rabbit distal femora, and found absence of bone differentiation toward the joint surface.[94] They concluded that the synovial environment seemed to prevent bone formation otherwise induced by DBM. The present study investigated cortical DBM for talar OCDs and found no beneficial effect. The differences in outcome between our study and the former studies might be due to

the fact that we studied larger and older animals with larger OCDs. Additionally, an important difference between the studies is the joint investigated; the knee and ankle joints differ in congruency, cartilage thickness, and loading characteristics.[85,234,399] These joints might thus not be reliably compared in osteochondral defect healing models.

In general, the effectiveness of DBM depends on numerous variables, including the age of the donor,[347] the tissue bank and the lot,[172,173,450] prolonged heat treatment,[196] the size or shape of the graft particles,[155] the nature of the carrier material, the extent of residual bone mineral content,[459] and the method of sterilization.[171] However, most of these variables are not applicable to the commercially available DBM used in the current study. This type of DBM has shown consistent composition and proven effectiveness in previous studies using a heterotopic bone formation model and an in vitro model.[173,317,318] Possibly, the natural circumstances of the joint (i.e., high loading forces and possible intrusion of fluid into the OCD) might preclude the effectiveness of the DBM in the present study. Remnants of the DBM were found in two specimens, suggesting not all the material had remodeled. Furthermore, DBM was used as a xenograft; that is, human DBM was implanted in caprine OCDs. This might theoretically influence the effectiveness of DBM. However, the use of human DBM in animals did not seem to affect positive results in other studies.[173,324] Hence, this aspect is probably not a good explanation for the lack of effectiveness. The immune response of the animals was not clearly related to the implantation of DBM; macrophages were observed in one DBM specimen and in four control specimens.

The addition of PRP to DBM has led to equivocal results in the literature. Butcher et al. found a significant increase in DNA content and mineralization level by adding PRP to DBM in vitro.[67] Likewise, a viable osteochondral construct has been created with DBM and PRP ex vivo.[249] In contrast, Ranly et al. found a neutral or even inhibitory effect of PRP to the ectopic formation of bone induced by DBM in a nude mouse model.[324] This negative effect of PRP to DBM may have been caused by the activation with thrombin.[173] Han et al. demonstrated that PRP can increase the osteoinductivity of DBM, but only when it has not been activated by thrombin.[173] Even though in the present study the PRP was not activated with thrombin either, a beneficial effect of PRP could not be demonstrated.

Strengths of this study include the use of an established model with a large animal; a power analysis to identify the minimal number of animals; an internal control in each goat; and numerous qualitative and quantitative analyses after relatively long follow-up.

The study also has limitations. There was a single follow-up assessment of 24 weeks.

This way, the number of goats required for the study could be limited to 16. Instead of using additional animals for shorter follow-up assessments, fluorochrome labels were injected at various moments during the follow-up period. This allowed analysis of the speed of repair during the recovery period and made the inclusion of additional animals unnecessary. Another limitation was the variable concentration of platelets in the PRP. The mean concentration was approximately four times that of unprepared caprine whole blood, but the dispersion was high. This variation was also observed in previous studies,[120,275] and might be due to either the preparation or the analysis of PRP. Although both systems – GPS II for preparation and XE-5000 for analysis – have been developed for human blood, others have successfully used them in animals; e.g., a GPS II system for bovine blood (increasing the platelet concentration fourfold),[454] and an XE-2100 analyzer for rat PRP.[208] We therefore believe the systems can be used in other species. We also believe the observed variation in platelet concentration does not affect the conclusions, as there was no statistically significant difference ($p = 1.0$) in outcome between specimens with high concentrations and those with low concentrations of PRP. Besides, the ideal concentration of PRP remains unknown.[136,195] Further studies are indicated to determine the optimal concentration of PRP as well as the ideal preparation of DBM before they can be uniformly investigated in (pre)clinical studies.

Conclusion

DBM with or without PRP was not beneficial in the treatment of OCDs of the talus in goats.

Acknowledgment

Biomet BV, Dordrecht, the Netherlands, is gratefully acknowledged for financial support of the study and supply of the demineralized bone matrix and gravitational platelet system. The company was not involved in the study design; in the collection, analysis and interpretation of data; in the writing of the report; or in the decision to submit the paper for publication.

Part V
Outcome measures

Chapter 15

Outcome measures

Inger N. Sierevelt
Christiaan J.A. van Bergen
Karin Grävare Silbernagel
Daniël Haverkamp
Jón Karlsson

Book chapter in: C.N. van Dijk and J.G. Kennedy (eds):
Talar OCD. With special emphasis on diagnosis, planning and rehabilitation
in press.

Take home messages

- The AOFAS score is a frequently used outcome measure for talar OCD, but some concerns of the score are discussed
- The FAOS and the FAAM are functional patient-reported outcome scores that are useful in the clinical assessment of patients with talar OCD
- The 11-point NRS is a suitable, valid, and practical scale to assess pain intensity
- Postoperative imaging can be used for objective assessment of surgical repair

Introduction

Outcome assessment is critical in evaluating the efficacy of orthopedic procedures. Questionnaires are used to assess the patient's perspective on the degree of impairment, pain, disability, and quality of life. Many outcome scores have been developed to assess the effect of orthopedic interventions for various ankle disorders. Scoring systems that have been used in the evaluation of talar osteochondral defects (OCDs) are presented in a systematic review[458]. The selection of the appropriate outcome measure is not only dependent on the patient population, but to a greater extent on the outcome of interest.

To be able to evaluate treatment effect, the outcome measure should be reliable, valid, and sensitive to changes over time.[383] Additional information on minimal clinically important changes for the outcome measures in this specific patient population may be important to evaluate treatment results in the day-by-day clinical practice.

Frequently used outcome scores are discussed in this chapter (Table 1). In addition to these clinical outcome measures, the authors discuss scoring systems based on postoperative imaging after the treatment of talar OCDs (Table 2).

Clinical and functional outcome measures

The American Orthopaedic Foot and Ankle Society ankle-hindfoot score

The American Orthopaedic Foot and Ankle Society (AOFAS) has developed four rating systems, in which the clinical status of the ankle and foot is reported[217]. In the original publication, the AOFAS ankle-hindfoot score was described to be used for ankle replacement, ankle arthrodesis, ankle instability operations, subtalar arthrodesis, subtalar instability operations, talonavicular arthrodesis, calcaneocuboid arthrodesis, calcaneal osteotomy, calcaneus fracture, talus fracture, and ankle fractures[217]. This scale incorporates both subjective and objective factors with a maximal score of 100, indicating no symptoms or impairments. The scale includes nine items that can be divided into three subscales (pain, function, and alignment). Pain consists of one item with a maximal score of 40, indicating no pain. Function consists of seven items with a maximal score of 50, indicating full function. Alignment consists of one item with a maximal score of 10, indicating good alignment.

The AOFAS ankle-hindfoot score, as a complete score, has been shown to be valid [265,364,447]. The score has shown good responsiveness over time in two studies, with reported effect sizes of 1.69[265] and 1.12[365]. The subjective

portion of the scale has been shown to be valid and reliable[192]. The objective portion of the scale has not been evaluated for reliability. This is one of the main criticisms of the AOFAS score. The second major concern of the AOFAS score is the weighting and calculations of the items; for example, high scores are obtained relatively easily (i.e., ceiling effect). Furthermore, the subscale pain is heavily weighted (40 points), and there is a 20-point difference between rating pain as severe (almost always present) and moderate (daily). To establish reliability, validity, and responsiveness, the scale has been evaluated related to a wide spectrum of diagnoses, such as general ankle-hindfoot complaints[364], pending ankle or foot surgery[192], surgically treated calcaneal fractures[447] and end-stage ankle arthritis[265]. However, there is no study that has evaluated the psychometric properties in patients with talar OCD.

The Foot and Ankle Outcome Score

The Foot and Ankle Outcome Score (FAOS)[336] is a patient-reported score, which evaluates symptoms and functional limitations related to the foot and ankle (www.koos.nu). It includes five different subscales: pain (nine items), other symptoms (stiffness, swelling and range of motion; seven items), activities of daily living (17 items), sports and recreational activities (five items), and foot and ankle related quality of life (four items). The items are scored on a 0-4 point scale and then normalized, resulting in a subscale score of 0-100. A score of 100 equals no symptoms or difficulty with activities. The FAOS is based on the Knee injury and Osteoarthritis Outcome Score (KOOS) and has been shown to have good validity and reliability in patients with ankle injury[336]. When used as an outcome measure for patients with Achilles tendinopathy, it has been shown to be responsive to changes over time[218,337]. No study has evaluated the minimal clinically important difference, nor have the reliability or validity been investigated specifically for talar OCD. The FAOS is available in numerous languages (www.koos.nu), enabling its use in international multicenter studies.

The Hannover Ankle Score

The Hannover Ankle score was developed by the Medizinischen Hochschule Hannover, therefore it can also be found as the Medizinischen Hochschule Hannover Ankle score or MHH score.

The Hannover Ankle Score consist of 20 questions with five graded response options that are filled out by the patient. The score consists of three domains: pain (five questions), swelling (five questions) and function (10 questions). These questions result in a score between 0 and 100.

The score was developed and first mentioned in a study by Thermann and co-workers[386]. It is based on the scales for the measurement of severity of symptoms and functional status by Levine and co-workers, which was designed for carpal tunnel syndrome[247]. The English version can be found in the initial publication. However, the questionnaire used in these patients was a German version. No translation protocols were mentioned. Thus, this questionnaire has not been designed according to the methodological guidelines, nor has it been properly validated. Only a test-retest reliability coefficient of 0.91 was reported[388].

The Foot and Ankle Ability Measure

The Foot and Ankle Ability Measure (FAAM) is a patient-reported questionnaire and was designed at the University of Pittsburgh. Martin and co-workers in 2005 thoroughly described the design and validation process[273]. The score was designed to evaluate changes in self-reported physical function in individuals with leg, ankle, and foot musculoskeletal

Table 1. Overview of clinical and functional outcome scores for foot and ankle

Foot and Ankle Outcome Score[336]
Symptoms
Do you have swelling in your foot/ankle?
Do you feel grinding, hear clicking or any other type of noise when your foot/ankle moves?
Does your foot/ankle catch or hang up when moving?
Can you straighten your foot/ankle fully?
Can you bend your foot/ankle fully?
How severe is your foot/ankle stiffness after first wakening in the morning?
How severe is your foot/ankle stiffness after sitting, lying or resting later in the day?
Pain
How often do you experience foot/ankle pain?
Twisting/pivoting on your foot/ankle
Straightening foot/ankle fully
Bending foot/ankle fully
Walking on flat surface
Going up or down stairs
At night while in bed
Sitting or lying
Standing upright
Function, Daily living
Descending stairs
Ascending stairs
Rising from sitting
Standing
Bending to floor/pick up an object
Walking on flat surface
Getting in/out of car
Going shopping
Putting on socks/stockings
Rising from bed
Taking off socks/stockings
Lying in bed (turning over, maintaining foot/ankle position)
Getting in/out of bath
Sitting
Getting on/off toilet
Heavy domestic duties (moving heavy boxes, scrubbing floors, etc)
Light domestic duties (cooking, dusting, etc)
Function, Sports and recreational activities
Squatting
Running
Jumping
Twisting/pivoting on your injured foot/ankle
Kneeling
Quality of Life
How often are you aware of your foot/ankle problem?
Have you modified your life style to avoid potentially damaging activities to your foot/ankle?
How much are you troubled with lack of confidence in your foot/ankle?
In general, how much difficulty do you have with your foot/ankle?
AOFAS ankle-hindfoot score[217]
Pain
Function
Activity limitations, support requirement
Maximum walking distance
Walking surfaces
Gait abnormality
Sagittal motion (flexion plus extension)
Hindfoot motion (inversion plus eversion)
Ankle-hindfoot stability (anteroposterior, varus-valgus)
Alignment

Foot and Ankle Ability Measure[273]
Foot and Ankle Ability Measure (FAAM)
Standing
Walking on even ground
Walking on even ground without shoes
Walking up hills
Walking down hills
Going up stairs
Going down stairs
Walking on uneven ground
Stepping up and down curbs
Squatting
Coming up on your toes
Walking initially
Walking 5 min or less
Walking approximately 10 min
Walking 15 min or greater
Home Responsibilities
Activities of daily living
Personal care
Light to moderate work (standing, walking)
Heavy work (push/pulling ,climbing, carrying)
Recreational activities
FAAM Sports Scale
Running
Jumping
Landing
Starting and stopping quickly
Cutting/lateral movements
Low impact activities
Ability to perform activity with your normal technique
Ability to participate in your desired sport as long as you would like
Hannover Questionnaire[386]
Symptoms Severity Scale
How severe is your pain in the evening?
How often did you have pain within the past two weeks?
Do you feel any pain during the day?
How often do you feel pain during the day?
How long does your pain last during the day?
Do you have swelling around your ankle and/or foot in the evening?
How often did you have swelling around your ankle and/or foot during the past two weeks in the evening?
How often do you have swelling of your ankle and/or foot during the day?
Do you feel any stiffness in your foot or ankle?
Does the stiffness bother you?
Questionnaire functional status
Do you have difficulties to climb stairs?
Do you have difficulties driving a car (brake, clutch, gas pedal)?
Do you have difficulties to walk on uneven or slippery ground?
Are you able to walk fast or do jogging?
Are you able to jump (small ditch or puddle)?
You have difficulties with single leg stance?
How long does it take for your leg to get fatigued?
Do you feel your operated leg is more weak than the uninjured one?
How you would describe your gait?
Do you have problems wearing conventional shoes?
Ogilvie-Harris score[304]
Pain
Swelling
Stiffness
Limping
Activity

Table 2. Overview of several radiographic (Van Dijk, modified Takakura, modified Kellgren Lawrence) and MRI (MOCART) scoring systems for the ankle joint.

Van Dijk Scale[425]
(0) Normal joint or subchondral sclerosis
(I) Osteophytes without joint space narrowing
(II) Joint space narrowing with or without osteophytes
(III) (Sub)total disappearance or deformation of the joint space
Modified Takakura Scale[380]
(1) No joint space narrowing but early sclerosis and osteophyte formation
(2) Narrowing of the joint space medially
(3a) Obliteration of the joint space limited to the facet of medial malleolus with subchondral bone contact
(3b) Obliteration of the joint space advanced to the roof of the talar dome with subchondral bone contact
Modified Kellgren-Lawrence Scale[212]
(0) No radiographic findings of osteoarthritis
(1) Minute osteophytes of doubtful clinical significance
(2) Definite osteophytes with unimpaired joint space
(3) Definite osteophytes with moderate joint space narrowing
(4) Definite osteophytes with severe joint space narrowing and subchondral sclerosis

Magnetic resonance observation of cartilage repair tissue[270]
Degree of defect repair and filling of the defect
Complete (on a level with adjacent cartilage)
Hypertrophy (over the level of the adjacent cartilage)
Incomplete (under the level of the adjacent cartilage; underfilling)
>50% of the adjacent cartilage
<50% of the adjacent cartilage
Subchondral bone exposed (complete delamination or dislocation
and/or loose body)
Integration to border zone
Complete (complete integration with adjacent cartilage)
Incomplete (incomplete integration with adjacent cartilage)
Demarcating border visible (split-like)
Defect visible
<50% of the length of the repair tissue
>50% of the length of the repair tissue
Surface of the repair tissue
Surface intact (lamina splendens intact)
Surface damaged (fibrillations, fissures and ulcerations)
<50% of repair tissue depth
>50% of repair tissue depth or total degeneration
Structure of the repair tissue
Homogenous
Inhomogenous or cleft formation
Signal intensity of the repair tissue
Dual T2-FSE
Isointense
Moderately hyperintense
Markedly hyperintense
3D-GE-FS
Isointense
Moderately hypointense
Markedly hypointense
Subchondral lamina
Intact
Not intact
Subchondral bone
Intact
Non-intact (edema, granulation tissue, cysts, sclerosis)
Adhesions
No
Yes
Effusion
No
Yes

disorders. The questionnaire was constructed by using the following four steps to develop a self-reported evaluative instrument: 1) generation of potential items, 2) initial item reduction, 3) final item reduction, and 4) acquisition of validity evidence to support interpretation of the score[273].

The FAAM comprises two separately scored subscales; the activities of daily living (ADL) subscale (21 items) and the sports subscale (eight items). Each item is scored on a five-point Likert scale from 4 to 0, with 4 being "no difficulty" and 0 being "unable to do". Items without a response are marked as not applicable and are not counted. The total number of items with a response is multiplied by four to get the highest potential score. The total item score is divided by the highest potential score and then multiplied by 100 to produce the FAAM score that ranges between 0 and 100. A higher score represents a higher level of physical function for both the ADL and sports subscales. The minimal clinically important differences for the FAAM are 8 and 9 points for the ADL and sports subscales, respectively.

Since its introduction, the construct validity, reliability, and responsiveness have been tested for several indications. In all these indications, the FAAM has been shown to be a valid subjective measurement tool[70,159,274]. There is, however, no specific information in the literature on psychometric properties for talar OCD. The FAAM has been translated and validated into several languages[55,277,295].

In conclusion, the FAAM is a well-validated questionnaire suitable for several foot and ankle pathologies.

The Ogilvie-Harris and Berndt and Harty scores

Both the Ogilvie-Harris and Berndt and Harty scores are simple scoring systems to evaluate the effect of treatment. They are specifically useful to provide a success rate rather than a score.

The Ogilvie-Harris score consists of five items, including pain, swelling, stiffness, limping, and activity[304]. Either the patient or the examiner rates each item as excellent, good, fair, or poor. The lowest grade of each of the five items determines the final score.

The Berndt and Harty outcome question was specifically introduced for ankle OCDs. It is a single question with three possible answers, which allows patients to categorize their ankles into good, fair, or poor[49]. The score was slightly modified in 2003 because the original language was confusing[190]. In this modified score, patients with a "good" outcome have no symptoms of pain, swelling or instability, or experience slightly annoying, but not disabling, symptoms; patients with a "fair" outcome report that the symptoms are somewhat improved, although some disability problems persist; a "poor" outcome indicates that the overall symptoms remain unchanged[190].

Both the Ogilvie-Harris and the Berndt and Harty scores have been used in various studies on the treatment of osteochondral ankle defects[190,346,416], which makes it possible to compare the results of different studies. However, neither score has been validated. The Berndt and Harty outcome question has been shown to have a good correlation with both the single assessment numeric evaluation ($r = 0.81$) and the Martin outcome system ($r = 0.69$)[190].

Pain assessment

Measurement of pain intensity is a quantitative estimate of the subjective interpretation of the severity of the pain experienced by the patient. The most frequently used methods to assess pain intensity are (1) the visual analogue scale (VAS), (2) the numeric rating scale (NRS), and (3) the verbal rating scale (VRS). All pain rating

scales have been extensively studied in several different populations, and validity and reliability have been demonstrated[185]. However, there is high variation in pain descriptors of the scales, time frames used to assess pain intensity (e.g., last week, last month), and specific situations for which pain intensity has to be assessed (e.g., rest, activity).

Visual analogue scale

The VAS is a 100-mm line that represents the severity of the pain; the ends of the scale are anchored by two extremes of pain, such as "no pain" on one side and "worst imaginable pain" on the other side. The patient is asked to mark the line to indicate the pain intensity.

Various minimal clinically important differences are proposed for the VAS for musculoskeletal conditions. A minimal clinically important difference of 15 mm was proposed for low back pain (30% from baseline)[307], 20 mm for knee osteoarthritis (41% from baseline), and 15 mm for hip osteoarthritis (32% from baseline)[401].

Numeric rating scale

The NRS is an 11-, 21-, or 101-point scale where the end points often are the extremes "no pain" and "worst imaginable pain" or "unbearable pain". The NRS measures pain severity by asking the patient to select a number that represents the severity of the pain. The NRS can be administered graphically (NRS) or verbally (VNRS). The 11-point (V) NRS (0 – 10) is used most frequently [185].

The minimal clinically important difference of the 11-point NRS is 2 points, reported for both low back pain[307] and chronic musculoskeletal pain (rheumatoid arthritis; knee, hip, and hand osteoarthritis; and ankylosing spondilitis)[339], both implying a change from baseline of approximately 30%.

Verbal rating scale

The VRS consists of a list of adjectives that are commonly used to describe increasing pain intensity. It should comprise the extremes of the scale, such as "no pain" and "worst imaginable pain". The amount of response options can vary, but has to be sufficient to capture the gradations of pain intensities experienced by the patient. Rank numbers are assigned to response options, with highest numbers indicating most pain.

All three scales perform generally well, although specific studies on reliability, validity and minimal clinically important difference for patients with talar OCD are lacking. All scales are sensitive to changes over time [60,261,360]. The VRS, however, is slightly less sensitive than the NRS and the VAS[60,130,261], possibly due to the limited amount of response options. The NRS and the VRS are both easy to administer with good compliance. The VAS scale appears to be more complicated than NRS and VRS[185]. Despite the fact that the scales are highly correlated, they can not be used interchangeably [260,360].

Since the psychometric properties of the pain scales are sufficient, the choice for the type of scale can be based on practical considerations, such as ease of administration and type of population. The authors prefer the NRS because of its ease and compliance.

Postoperative imaging

Radiography

Radiographs are frequently obtained in the postoperative assessment of talar OCDs, especially to evaluate degenerative changes in the joint. Several radiographic grading systems have been developed for the osteoarthritic ankle joint[211,375,425]. The scales focus on the presence

of osteophytes and joint space narrowing. The Kellgren and Lawrence system was not designed specifically for the ankle[211]. The Takakura system focuses mainly on the medial joint space[375]. The van Dijk OA classification evaluates the complete talocrural joint, and has been used for the evaluation of talar OCD[346,416].

Moon and co-workers compared the van Dijk scale[425], the modified Kellgren-Lawrence scale[212], and modified Takakura[380] scales, and concluded that all these scales were reliable and valid[291]. Interobserver and intraobserver comparisons (weighted Kappa) of each scale were found to be satisfactory (Kellgren and Lawrence, 0.51 to 0.81; Takakura, 0.65 to 0.88; van Dijk, 0.64 to 0.89). However, the predictability of the scales for cartilage damage, as observed by arthroscopy, was only moderate (intraclass correlation coefficients, 0.42 to 0.51)[291].

Computed tomography

To objectively assess the bone repair, multislice helical computed tomography (CT) scans can be obtained[410]. CT has been shown to be accurate in the follow-up of talar OCDs[460]. The scanning protocol involves "ultra high resolution" axial slices with an increment of 0.3 mm and a thickness of 0.6 mm, and multi-planar coronal and sagittal 1-mm reconstructions[408]. One can measure the completeness, thickness, and level of the subchondral plate (i.e., flush, depressed, or proud), as well as bone volume filling of the defect and postoperative loose bony particles[409,410]. However, to our knowledge, a postoperative grading system based on CT is unavailable.

Magnetic resonance imaging

Magnetic resonance imaging (MRI) evaluation of OCD repair tissue has gained popularity in recent years. The scanning protocol incorporates proton density and fast spin-echo acquisitions for cartilage evaluation[270]. Some investigators have quantified MRI results by self-developed criteria[44,193], but a more objective, well-known, and frequently used method is the magnetic resonance observation of cartilage repair tissue (MOCART)[270,271]. Nine variables describe the morphology and signal intensity of the repair tissue compared with the adjacent native cartilage, the degree of filling of the defect, the integration to the border zone, the description of the surface and structure, the signal intensity, the status of the subchondral lamina and subchondral bone, the appearance of adhesions and the presence of synovitis[270]. This system has good interobserver reliability, with intraclass correlation coefficients of >0.81 in eight of nine variables[271]. However, the association of the MOCART with the clinical situation is not exactly clear. In a study by Aurich and co-workers there was no relation between the MOCART and clinical outcome after matrix-associated chondrocyte implantation of the talus[27]. In another study, three out of five variables of the modified MOCART showed good correlation with second-look arthroscopy after autologous chondrocyte implantation in the ankle, while two out of five variables showed poor correlation[245].

Conclusions and recommendations

Valid and reliable outcome measures are available for several ankle conditions. However, none of the clinical and functional outcome scores have been psychometrically investigated for the specific patient population with talar OCD. The AOFAS has been used most frequently in studies on the treatment of talar OCD[458], but has some serious concerns. Both the FAAM and the FAOS are suitable questionnaires for patients with various ankle conditions. However, minimal clinically important differences of these scales

are desirable for proper evaluation of outcomes of OCD treatment.

Pain assessment for patients with talar OCD is important since pain is the predominant symptom. Although the described pain scales have been properly validated, they lack information on the minimal clinically important difference for this patient group. Most important in a clinical or research setting is the use of standardized pain descriptors, clear time frames, and unambiguous description concerning the context of pain assessment. The 11-point NRS has, in our opinion, some advantages and would be the most practical and valid choice for the use of pain assessment.

In addition to specific ankle scores, the authors recommend to use a general quality-of-life score in clinical studies, such as the short form-36 or the EuroQoL[121,445].

Postoperative imaging can be a useful adjunct to clinical outcome scoring.

Chapter 16

Translation and validation of the German Foot and Ankle Outcome Score

Christiaan J.A. van Bergen
Inger N. Sierevelt
Paul Hoogervorst
Hazibullah Waizy
C. Niek van Dijk
Christoph Becher

Submitted.

Abstract

Purpose

Outcome assessment is critical in evaluating the efficacy of orthopaedic procedures. The Foot and Ankle Outcome Score (FAOS) is a 42-item questionnaire divided into five subscales, which has been validated in several languages. Germany has no validated outcome score for general foot and ankle pathology. The aim of this study was to develop a German version of the FAOS and to investigate its psychometric properties.

Methods

Forward and backward translation was executed according to official guidelines. The final version of the FAOS was investigated in 150 patients with various foot and ankle disorders. All patients completed the FAOS, Short Form-36, numeric rating scales for pain and disability, and the Hannover questionnaire. The FAOS was re-administered after one week. Test-retest reliability, internal consistency, minimal detectable change, construct validity, and floor and ceiling effects were analyzed.

Results

Test-retest reliability and internal consistency of each subscale were excellent (intraclass correlation coefficient, 0.88 to 0.95; Cronbach's alpha, 0.94 to 0.98). The minimal detectable changes of each subscale were 17.1 to 20.8 at the individual level and 2.0 to 2.4 at group level. There were moderate to strong correlations between FAOS subscales and physical outcomes and low to moderate correlations between FAOS subscales and mental outcomes. Floor and ceiling effects were not present.

Conclusion

The German version of the FAOS is a reliable and valid instrument for use in foot and ankle patients.

Introduction

Outcome assessment is critical in evaluating the efficacy of orthopaedic procedures. The assessment of outcome from the patient's perspective becomes more recognized.[115] Questionnaires are used to asses the patient's perspective on the degree of impairment, pain, disabilities, and quality of life. Translation and validation of the original questionnaire into the target language are essential for the conduction of multinational studies and for the comparison of outcomes from different countries.

There are few validated outcome measures for disability of the foot and ankle.[115] The Foot and Ankle Outcome Score (FAOS) is a valid and reliable instrument.[115,336] The score is available in English, Swedish, Portuguese, Persian, Turkish, and Dutch.[5,207,297,336,356] Germany has the largest population of Europe but, to our knowledge, has no validated outcome score for general foot and ankle pathology. Therefore, the aim of

this study was to translate and validate the FAOS into German, enabling its use in the German-speaking population.

Methods

Translation procedure

Forward and backward translation was executed according to official guidelines.[449] Two bilingual translators with different profiles (one physician) whose native language was German produced two independent forward translations. A synthesis of these translations was conducted. Two other translators without medical background, with English as the native language and blinded to the original version, then translated the questionnaire back into the original language. A committee composed of the translators and a German orthopaedic surgeon consolidated all the versions of the questionnaire and developed the final version for field testing (Supplement). The last step of the translation procedure was the pretesting on several random patients. The patients were asked whether they understood all the items and whether they had suggestions for improvement. No difficulties were encountered, and changes to the final version were not indicated (Supplement).

Validation procedure

A random sample of 150 outpatients with chronic foot and ankle related disorders were included in the study at a single institution. Exclusion criteria were inability to understand or complete the questionnaires, or refusal to sign informed consent. There were 65 male and 85 female patients with a mean age of 48 ± 16 years (range, 18 – 79 years). The diagnoses of the ankle included osteochondral defects, osteoarthritis, anterior or posterior impingement, instability, loose bodies, and tendonitis; diagnoses of the foot included plantar fasciitis, metatarsalgia, and pes planus. About 80% were preoperative or nonoperative patients, and 20% were postoperative during routine controls (not in the early postoperative period). The study protocol was approved by the local Medical Ethics Committee (Nr. 720/2010). All patients signed informed consent.

Each patient completed a package of questionnaires containing the FAOS, Short Form-36 (SF-36), numeric rating scale (NRS) for pain and disability, and Hannover questionnaire. The FAOS was re-administered under similar conditions with a 1-week interval. The patients had to indicate whether any change in the (extent of) symptoms had occurred during the interval.

Instruments

The FAOS is a 42-item questionnaire intended to evaluate symptoms and functional limitations related to the foot and ankle.[336] It consists of five subscales: pain; other symptoms; activities of daily living (ADL); sport and recreational activities; and foot- and ankle-related quality of life (QoL). Patients score each question on a Likert scale (no, mild, moderate, severe, extreme) resulting in a score ranging from 0 to 4. The scores of the subscales are calculated by the sum of the items included. The total scores are then transformed to a scale from 0 to 100. Higher total values indicate lesser problems and/or functional limitations.

The SF-36 is a widely used, patient-administered, generic health related quality of life instrument,[445] which has been translated and validated into German.[65] It comprises 36 items across eight subscales, which are each calculated on a 0 to 100 scale (100 indicating no symptoms and 0 indicating extreme symptoms).

Numeric rating scales (NRS) were used to determine the severity of pain and disability

of the ankle and foot. A score of 0 accounts for no pain or disability; a score of 10 represents the most severe pain or disability imaginable.

The Hannover questionnaire rates patients' complaints and functional status based on a severity-symptom scale and functional status. It contains 20 subjective questions for the patient with five possible answers to each. A test-retest reliability of r = 0.91 has been reported but the score has not been validated.[387]

Statistical analysis

The FAOS subscale scores were calculated with use of formulas provided by the developers.[5] Missing data and double marks were treated as outlined by the developers.[5]

Psychometrics is the process that allows researchers to apply scientific methodology to the measurement of subjective outcomes. The psychometric properties of a questionnaire define how well a questionnaire measures what it is supposed to measure. Reliability and validity of the German version of the FAOS were tested with use of SPSS software (version 19.0; Chicago, Illinois, USA).

The test-retest reliability was assessed by calculation of intraclass correlation coefficients ($ICC_{agreement}$, two-way random effects model).[355,383] The test-retest reliability was considered good if the ICC is 0.40 – 0.75 and excellent if the ICC > 0.75.[134] Systematic differences between the first and second test were assessed with use of paired t-tests.

Internal consistency determines whether the questions cover the same construct. Cronbach's alpha was calculated to assess the internal consistency of each subscale of the FAOS.[89] This coefficient addresses the homogeneity of the questions included in a questionnaire. Cronbach's alphas of 0.7, 0.8, and 0.9 are considered to represent a fair, good, and excellent degree of internal consistency, respectively.[53]

There is a 95% confidence rate that the health status of a patient improves or deteriorates when the change in scores exceeds the minimal detectable change. The minimal detectable change (MDC) at the individual level was calculated as $1.96 \times \sqrt{2} \times$ standard error of measurement (i.e., the square root of the within-subject variance).[383] The MDC at group level was calculated by dividing the MDC at the individual level by $\sqrt{n}$.[383]

Validity relates to the ability of a questionnaire to measure the outcome parameter of interest. Construct validity refers to the association with other measures in a manner that is consistent with theoretically derived hypotheses, in the absence of a "gold standard".[383] The FAOS subscales were compared with the SF-36, NRS pain and disability, and Hannover questionnaire. Pearson correlation coefficients were calculated to determine construct validity of the FAOS. Correlation coefficients of <0.30, 0.30 – 0.60, and >0.60, are considered low, moderate, and strong, respectively.[207] Convergent and discriminate validity were evaluated (i.e., are correlations high where they are expected to be high, and low where they are expected to be low). We hypothesized that correlations of FAOS subscales with the physical outcomes (SF-36 subscales Physical functioning, Role physical, and Bodily pain; NRS Pain and Disability; and Hannover questionnaire) would be higher than correlations with the mental outcomes (other SF-36 subscales).

Floor and ceiling effects were registered for each scale. These effects are considered to be present if the amount of minimal or maximal scores exceeds 15%.[383]

Results

In the complete study population, the mean FAOS subscale Pain was 59.5 ± 22.4 (range,

13.9 – 100); Symptoms was 62.3 ± 20.9 (range, 17.9 – 100); ADL was 70.3 ± 21.9 (range, 7.4 – 100); Sport was 46.2 ± 28.7 (range, 0 – 100); and QoL was 36.9 ± 21.3 (range, 0 – 100). A total of 158 individual items were missing, which corresponds to 2.5% of missing data (158 items in 150 patients × 42 items). Each subscale score of all patients could be calculated.

One-hundred and eighteen patients (79%) completed the second FAOS after a week. Of these, 42 indicated that the (extent of) symptoms had changed since the first questionnaire. Therefore, data of 76 patients (51%) were used to calculate the reliability.

Test-retest reliability of each subscale and internal consistency were excellent (Table 1). The MDCs at the individual level were between 17.1 and 20.8; those at group level were between 2.0 and 2.4 (see Table 1).

There were moderate to strong correlations between FAOS subscales and SF-36 Physical functioning, Role physical, and Bodily pain; NRS Pain and Disability; and Hannover questionnaire (Table 2). There were low to moderate

Table 1. FAOS subscale scores (n = 76), test-retest reliability (n = 76), internal consistency (n = 150), and minimal detectable change (n = 76)

FAOS subscale	Test (mean ± SD)	Retest (mean ± SD)	ICC (95% CI)	Cronbach's alpha	Systematic difference	$MDC_{individual}$	MDC_{group}
Pain	57.6 ± 23.0	58.7 ± 22.6	0.92 (0.88 - 0.95)	0.96	1.1 (p = 0.25)	18.1	2.1
Symptoms	60.2 ± 21.1	63.0 ± 22.5	0.88 (0.82 - 0.93)	0.94	2.8 (p = 0.06)	20.0	2.3
ADL	69.4 ± 22.6	68.7 ± 23.9	0.89 (0.83 - 0.93)	0.94	0.7 (p = 0.61)	20.8	2.4
Sport	47.1 ± 29,0	48.7 ± 29.9	0.95 (0.93 - 0.97)	0.98	1.6 (p = 0.21)	17.2	2.0
QoL	38.5 ± 23.8	39.3 ± 22.2	0.93 (0.90 - 0.96)	0.97	0.8 (p = 0.40)	17.1	2.0

ADL = activities of daily living, CI = confidence interval, ICC = intraclass correlation coefficient, MDC_{group} = minimal detectable change at group level, $MDC_{individual}$ = minimal detectable change at individual level, QoL = foot- and ankle-related quality of life, and SD = standard deviation.

Table 2. Construct validity. Correlation (Pearson correlation coefficient) between FAOS subscales and other outcome measures (n = 150)

	Subscale	Pain	Symptoms	ADL	Sport	QoL
SF-36	Physical functioning	0.66	0.58	0.79	0.75	0.63
	Role physical	0.33	0.34	0.54	0.53	0.43
	Bodily pain	0.80	0.59	0.68	0.62	0.66
	Social functioning	0.36	0.36	0.38	0.44	0.38
	Mental health	0.23	0.25	0.25	0.21	0.17
	Role emotional	0.19	0.27	0.30	0.34	0.27
	Vitality	0.21	0.22	0.26	0.21	0.26
	General health perceptions	0.25	0.40	0.42	0.32	0.41
NRS	Pain	-0.74	-0.47	-0.54	-0.52	-0.59
	Disability	-0.55	-0.51	-0.63	-0.58	-0.61
Hannover questionnaire		0.71	0.74	0.75	0.78	0.64

All correlations were statistically significant ($p < 0.05$).
ADL = activities of daily living, NRS = numeric rating scale, SF-36 = Short Form-36, and QoL = foot- and ankle-related quality of life.

correlations between FAOS subscales and SF-36 Social functioning, Mental health, Role emotional, Vitality, and General health perceptions.

There were no floor or ceiling effects. The lowest score was obtained by 0%, 0%, 0%, 5%, and 1% of the patients on the subscales Pain, Symptoms, ADL, Sport, and QoL, respectively. The highest score was obtained by 7%, 5%, 10%, 5%, and 5% of the patients on the subscales Pain, Symptoms, ADL, Sport, and QoL, respectively.

Discussion

A German version of the FAOS was developed in the first part of the present study. The translation process was executed according to official guidelines.[449] The translated version was tested in the second part of the study. According to the psychometric analyses, the translated version was shown a reliable and valid instrument for use in German-speaking patients with foot and ankle pathology.

Test-retest reliability and internal consistency of each subscale were excellent (see Table 1). There were moderate to strong correlations between FAOS subscales and physical outcomes, and there were low to moderate correlations between FAOS subscales and mental outcomes (see Table 2). In addition, no floor or ceiling effects were observed. According to the MDC, the FAOS may be more suitable for the evaluation at group level than at individual level. The relatively high MDC may be attributed to the diverse study population.[101]

Although only 76 of 150 patients were available for statistical analysis of test-retest reliability (due to a relatively low response rate of the second questionnaire or a changed situation), this number was well above the required number of 50.[383] Cross-cultural adaption of the questionnaire was deemed unnecessary, because the German population can be considered similar to the Swedish population of the original version.[336] Likewise, the patient burden imposed by administering the FAOS was not tested because it is considered to be identical to that of the original version (less than 10 min).[336]

Roos et al. invented the original English version (adapted from the Knee injury and Osteoarthritis Outcome Score).[336] They tested the Swedish version in 213 patients.[336] The psychometric properties were generally similar to the German version. Test-retest reliability varied from an ICC of 0.70 for ADL to 0.92 for QoL, and Cronbach's alpha varied from 0.88 for Symptoms to 0.97 for ADL. For construct validity, the FAOS subscales were compared with the Karlsson score. Spearman correlation coefficients of 0.58 to 0.67 were found. However, ceiling effects occurred in each subscale. The differences in ceiling effects between the original version and the developed translation may be contributed to the different study population. Roos et al. studied patients with previous ankle ligament reconstructions after a mean follow-up of 12 years, while our study population consisted of patients with a variety of foot and ankle disorders.

The original version has also been translated and validated into Turkish and Persian.[207,297] Karatepe et al. studied 55 Turkish patients with various foot and ankle disorders.[207] They found a test-retest reliability (ICC) of 0.70 to 0.96 and a Cronbach's alpha of 0.79 to 0.97 for each subscale. Correlations between FAOS and SF-36 subscales were comparable to those in our study. Floor or ceiling effects were not reported. Negahban from Iran validated the Persian version in 93 patients with foot and ankle disorders, mostly ankle sprain.[297] ICCs were excellent but two subscales had low internal consistency (Cronbach's alpha of 0.39 for Symptoms and 0.62 for Qol). The correlations between FAOS and several SF-36 subscales were generally somewhat lower than in our study. Floor and

ceiling effects were not present. Although the psychometric properties of the other languages are slightly inferior to the German version, all versions meet the quality criteria.[383] The previous studies and our study indicate that the FAOS can be regarded a reliable and valid international outcome measure.

Other outcome measures developed for the German foot and ankle patient are the Visual Analog Scale Foot and Ankle (VAS FA) and the Foot and Ankle Ability Measure (FAAM).[273,333] The VAS FA, however, is not available in other languages.[333,371] Furthermore, only the construct validity was reported in healthy individuals.[333] The FAAM is a reliable and valid international instrument with psychometric properties similar to the FAOS.[273,277,295] The score has two subscales (ADL and Sport). The English and Persian versions have been validated in a range of foot and ankle disorders. However, the German version has been validated only in chronic ankle instability.[273,277,295] In contrast, the FAOS has been validated in patients with various pathologic conditions.[74,207,267,297,336] Possible advantages of the FAOS over the FAAM are a larger number of subscales and a broader target population.

The principal limitation of the present study is the fact that the sensitivity to change (i.e., responsiveness and minimal clinically important change) of the FAOS after an intervention was not investigated. Further studies are required to assess the sensitivity to change.

In conclusion, the developed German version of the FAOS is a valid and reliable instrument for foot and ankle patients. Future use of the score will allow comparison with the international literature and the execution of international multicenter studies. Translation and validation into other languages will expand its applicability.

Supplement

Final translated version of the German Foot and Ankle Outcome Score

„FAOS“ Fragebogen Fuß & Sprunggelenk

Datum: _____/_____/_____ Geburtsdatum: _____/_____/_____

Name: _____

ANLEITUNG: Dieser Fragebogen stellt Ihnen Fragen zum Zustand Ihres Fuß und Sprunggelenks. Die dadurch gewonnenen Informationen erlauben uns Ihre Beurteilung von Ihrem Fuß und Sprunggelenk zu verfolgen und dokumentiert wie gut Sie in der Lage sind, Ihre üblichen Aktivitäten zu verrichten.
Beantworten Sie bitte jede Frage durch ankreuzen des zugehörigen Kästchens.
Bitte nur ein Kästchen pro Frage ankreuzen. Wenn Sie sich unsicher sind, wie Sie die Frage beantworten sollen, wählen Sie die Antwort aus, die Ihnen am zutreffendsten erscheint.

Symptome
Diese Fragen beziehen sich auf Ihre Fuß/Sprunggelenksbeschwerden während der **vergangenen Woche**.

S1. Hatten Sie Schwellungen an Ihrem Fuß/Sprunggelenk?

niemals	selten	manchmal	oft	immer
☐	☐	☐	☐	☐

S2. Fühlten Sie ein Mahlen, hörten Sie ein Klicken oder irgendein Geräusch, wenn Sie Ihren Fuß/Ihr Sprunggelenk bewegten?

niemals	selten	manchmal	oft	immer
☐	☐	☐	☐	☐

S3. Blieb Ihr Fuß/Sprunggelenk hängen, oder blockierte er/es bei Bewegung?

niemals	selten	manchmal	oft	immer
☐	☐	☐	☐	☐

S4. Konnten Sie Ihren Fuß/Ihr Sprunggelenk ganz ausstrecken?

immer	oft	manchmal	selten	niemals
☐	☐	☐	☐	☐

S5. Konnten Sie Ihren Fuß/Ihr Sprunggelenk ganz beugen?

immer	oft	manchmal	selten	niemals
☐	☐	☐	☐	☐

Steifigkeit

Die nachfolgenden Fragen betreffen die Steifigkeit in Ihrem Fuß/Sprunggelenk während der **letzten Woche**. Unter Steifigkeit versteht man ein Gefühl der Einschränkung oder Verlangsamung der Fähigkeit Ihre Gelenke zu bewegen.

S6. Wie stark war Ihre Fuß/Sprunggelenkssteifigkeit morgens direkt nach dem Aufstehen?

keine	schwach	mäßig	stark	sehr stark
☐	☐	☐	☐	☐

S7. Wie stark war Ihre Fuß/Sprunggelenksteifigkeit nach dem Sie saßen, lagen, oder sich im **Verlauf des Tages** ausruhten?

keine	schwach	mäßig	stark	sehr stark
☐	☐	☐	☐	☐

Schmerzen

P1. Wie oft haben Sie Schmerzen im Fuß/Sprunggelenk?

nie	monatlich	wöchentlich	täglich	immer
☐	☐	☐	☐	☐

Wie ausgeprägt waren Ihre Schmerzen in der **vergangenen Woche** als Sie z.B:?

P2. Sich im Fuß/Sprunggelenk drehten

keine	schwach	mäßig	stark	sehr stark
☐	☐	☐	☐	☐

P3. Ihren Fuß/Ihr Sprunggelenk ganz ausstreckten

keine	schwach	mäßig	stark	sehr stark
☐	☐	☐	☐	☐

P4. Ihren Fuß/Ihr Sprunggelenk ganz beugten

keine	schwach	mäßig	stark	sehr stark
☐	☐	☐	☐	☐

P5. Auf ebenem Boden gingen

keine	schwach	mäßig	stark	sehr stark
☐	☐	☐	☐	☐

P6. Treppen herauf oder herunterstiegen

keine	schwach	mäβig	stark	sehr stark
☐	☐	☐	☐	☐

P7. Nachts im Bett lagen

keine	schwach	mäβig	stark	sehr stark
☐	☐	☐	☐	☐

P8. Saßen oder lagen

keine	schwach	mäβig	stark	sehr stark
☐	☐	☐	☐	☐

P9. Aufrecht standen

keine	schwach	mäβig	stark	sehr stark
☐	☐	☐	☐	☐

Aktivitäten des täglichen Lebens

Die nachfolgenden Fragen beziehen sich auf Ihre körperliche Leistungsfähigkeit.
Hierunter verstehen wir Ihre Fähigkeit, sich selbständig zu bewegen bzw. sich selbst zu versorgen.
Für jede der nachfolgenden Aktivitäten geben Sie bitte das Ausmaß der Schwierigkeiten an, welche Sie aufgrund Ihres Fuß/Sprunggelenks innerhalb der **letzten Woche** erfahren haben.

Welche Schwierigkeiten hatten Sie in der **letzten Woche** als Sie z.B.:

A1. Treppen herunterstiegen

keine	wenig	einige	groβe	sehr groβe
☐	☐	☐	☐	☐

A2. Treppen heraufstiegen

keine	wenig	einige	groβe	sehr groβe
☐	☐	☐	☐	☐

A3. Vom Sitzen aufstanden

keine	wenig	einige	groβe	sehr groβe
☐	☐	☐	☐	☐

Welche Schwierigkeiten hatten Sie in der **letzten Woche** als Sie z.B.:

A4. Aufrecht standen

keine	wenig	einige	groβe	sehr groβe
☐	☐	☐	☐	☐

A5. Sich bückten um z.B. etwas vom Boden aufzuheben

keine	wenig	einige	große	sehr große
☐	☐	☐	☐	☐

A6. Auf ebenem Boden gingen

keine	wenig	einige	große	sehr große
☐	☐	☐	☐	☐

A7. Ins Auto ein- oder ausstiegen

keine	wenig	einige	große	sehr große
☐	☐	☐	☐	☐

A8. Einkaufen gingen

keine	wenig	einige	große	sehr große
☐	☐	☐	☐	☐

A9. Socken/Strümpfe anzogen

keine	wenig	einige	große	sehr große
☐	☐	☐	☐	☐

A10. Vom Bett aufstanden

keine	wenig	einige	große	sehr große
☐	☐	☐	☐	☐

A11. Socken/Strümpfe auszogen?

keine	wenig	einige	große	sehr große
☐	☐	☐	☐	☐

A12. Im Bett lagen und sich drehten, ohne den Fuß/Sprunggelenk dabei zu beugen

keine	wenig	einige	große	sehr große
☐	☐	☐	☐	☐

A13. In oder aus der Badewanne stiegen

keine	wenig	einige	große	sehr große
☐	☐	☐	☐	☐

A14. Saßen

keine	wenig	einige	große	sehr große
☐	☐	☐	☐	☐

A15. Sich auf die Toilette setzten oder aufstanden

keine	wenig	einige	große	sehr große
☐	☐	☐	☐	☐

A16. Schwere Hausarbeit verrichteten (schwere Kisten umstellen, Boden schrubben, etc)

keine	wenig	einige	große	sehr große
☐	☐	☐	☐	☐

A17. Leichte Hausarbeit verrichteten (kochen, Staub wischen, etc.)

keine	wenig	einige	große	sehr große
☐	☐	☐	☐	☐

Aktivitäten bei Sport und Freizeit

Die nachfolgenden Fragen beziehen sich auf Ihre körperliche Belastbarkeit im Rahmen von Sport- und Freizeitaktivitäten. Für jede der nachfolgenden Aktivitäten geben Sie bitte das Ausmaß der Schwierigkeiten an, welche Sie aufgrund Ihres Fuß/Sprunggelenks innerhalb der **letzten Woche** erfahren haben.

SP1. In die Hocke gingen

keine	wenig	einige	große	sehr große
☐	☐	☐	☐	☐

SP2. Rannten

keine	wenig	einige	große	sehr große
☐	☐	☐	☐	☐

SP3. Hüpften

keine	wenig	einige	große	sehr große
☐	☐	☐	☐	☐

SP4. Sich auf Ihrem kranken Fuß umdrehten

keine	wenig	einige	große	sehr große
☐	☐	☐	☐	☐

SP5. Sich hinknieten

keine	wenig	einige	große	sehr große
☐	☐	☐	☐	☐

Lebensqualität

Q1. Wie oft sind Sie sich Ihres Fuß/Sprunggelenksproblems bewusst?

nie	monatlich	wöchentlich	täglich	immer
☐	☐	☐	☐	☐

Q2. Haben Sie Ihre Lebensweise verändert, um eventuell Ihrem Fuß/Sprunggelenk schadende Tätigkeiten zu vermeiden?

gar nicht	wenig	etwas	stark	vollständig
☐	☐	☐	☐	☐

Q3. Wie sehr leiden Sie unter einem Mangel an Vertrauen und Zuversicht hinsichtlich Ihres Fuß/Sprunggelenks?

gar nicht	wenig	etwas	stark	sehr stark
☐	☐	☐	☐	☐

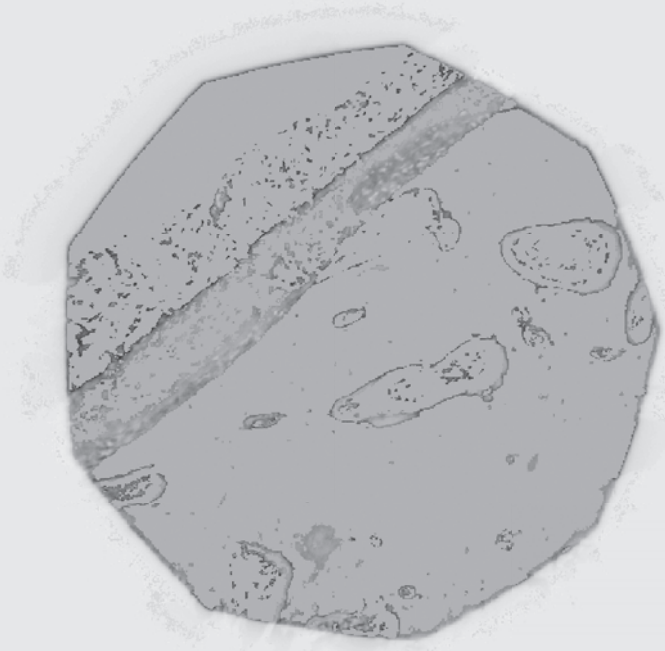
Q4. Wie würden Sie insgesamt die Schwierigkeiten bewerten die Sie durch Ihren Fuß/Ihr Sprunggelenk haben?

keine	wenig	einige	groβe	sehr groβe
☐	☐	☐	☐	☐

Vielen Dank für die Beantwortung aller Fragen.

Fragebogen und Anleitung sind auf der folgenden Internetadresse zu finden: www.koos.nu

General discussion and summary



Chapter 17

General discussion

General introduction

Osteochondral defects (OCDs) of the talar dome can be a disabling disorder that seriously affects the quality of life. Symptomatic OCDs pose a therapeutic challenge to the orthopaedic surgeon. Numerous treatment methods are available, each with advantages and disadvantages. This thesis aimed to evaluate and improve the current primary surgical treatment and to investigate alternative treatment methods.

Part I – Current concepts

Part I of the thesis reviewed the literature, presented a treatment algorithm, and discussed the use of arthroscopic ankle surgery. This part formed the basis for the remainder of the thesis. The review identified arthroscopic debridement and bone marrow stimulation as the primary surgical treatment of defects up to 15 mm. Osteochondral autograft transfer (OATS) and autologous chondrocyte implantation (ACI), with or without a cancellous bone graft, were recommended for secondary cases as well as large lesions.

The development of future treatment modalities described in chapter 2 included matrix-induced ACI, bone marrow-derived mesenchymal stem cells, biodegradable composite implants, correction osteotomy in the event of malalignment, metal resurfacing implants, demineralized bone matrix (DBM), and pulsed electromagnetic fields (PEMF). Some of these developments have become true options since the publication of the chapter. Different types of matrix-induced ACI have been reported in case series with two to 46 patients and a maximum follow-up of 3 years.[299] The overall success rate was 90% but a comparison between the studies was unreliable due to differences in indications, techniques, and outcome measures.[299] Furthermore, the analyses included duplicate follow-up publications from the same author. Bone marrow-derived cell transplantation loaded on a scaffold has been investigated in a series of 49 patients with a mean follow-up of 4 years.[150] Although the mean American Orthopaedic Foot and Ankle Society (AOFAS) ankle-hindfoot score improved from 64 ± 14 preoperatively to 82 ± 17 at the final follow-up, a significant decrease was evident between 2 and 4 years. This investigation thus showed promising results but questioned the durability of the technique.[150] Biodegradable composite implants have the advantages of a combined repair of cartilage and subchondral bone without the risk of donor site morbidity. However, after the report of four initial failures of commercially available composite implants, the procedure has been abandoned and scientific progress of this technique has decreased.[141] Correction osteotomy for OCDs in malaligned ankles seems a promising solution but clinical results of this procedure are not yet available.[113] The applicability of metal resurfacing implants, DBM, and PEMF was investigated in this thesis.

Part II – Primary arthroscopic debridement and bone marrow stimulation

Most OCDs can be treated by an anterior arthroscopic approach with the ankle in full plantar flexion. In case of posterior OCDs, it is challenging to treat the defect with this technique, since the ankle is a congruent joint with limited surgical access to the posterior talar surface. A posterior OCD can be approached with a two-portal hindfoot technique developed by van Dijk.[427]

The purpose of chapter 4 was to assess whether preoperative computed tomography (CT) of the ankle joint in full plantar flexion

was able to predict the anterior arthroscopic accessibility of talar OCDs. The study showed that measurements on CT scans of the ankle in full plantar flexion were a reliable and accurate preoperative method to determine the in situ arthroscopic location of talar OCDs. The findings of chapter 4 were followed by the study presented in chapter 5. The dual purpose of the study described in this chapter was (1) to quantify the anterior arthroscopic reach of the talus (i.e., proportion of the talar dome anterior to the anterior distal tibial rim) with the ankle in full plantar flexion, and (2) to identify predictive factors of the arthroscopic reach. The following conclusions were drawn: (1) almost half of the talar dome is accessible anterior to the anterior distal tibial rim, and (2) the clinical plantarflexion angle is an independent predictive factor of the arthroscopic reach of both the medial and lateral talar dome.

This study was the first to quantify the arthroscopic reach of the talus in a representative patient population. Previously, cadaveric studies investigated exposure of the talus with different open surgical approaches.[293,456] Muir et al. compared seven open approaches in nine cadaver specimens.[293] An anteromedial arthrotomy provided a mean access of 47% (range, 41% – 60%) of the medial talar dome in the sagittal plane. An anterolateral arthrotomy provided 43% (range, 37% – 50%) sagittal access of the lateral talar dome. Young et al. found that a median of 50% (range, 44% – 58%) of the anteroposterior medial talar dome length could be reached through an anteromedial approach.[456] The results of our study thus show similar results to the previous cadaveric studies. The added value is the use of a validated method and correlation with arthroscopy, a larger and representative study population, and the identification of predictive factors. The results may also be relevant for other procedures, such as OATS and metal resurfacing inlay implants. However, for these procedures the complete OCD has to be exposed, instead of only the anterior border.

The results of chapters 4 and 5 give direction to preoperative planning protocols of the surgical approach for OCDs. The defect can be accessed by anterior arthroscopy if its anterior border is in the anterior half of the talus and ankle motion is not restricted. In doubtful cases, a CT scan of the ankle in full plantar flexion can be obtained. If the anterior border of the OCD is behind the anterior distal tibial rim with the ankle in full plantar flexion, access by means of an anterior approach will depend on the joint opening on forced plantar flexion or distraction. In case of a stiff and highly stable joint and a posterior OCD, another approach is preferred, e.g., posterior arthroscopy.

The development of new techniques and instruments may reduce the necessity of full surgical exposure. A waterjet technique has been shown to produce cone-shaped holes in the subchondral bone of human and animal cadaveric calcanei.[103] The technique can possibly be applied via flexible tubings, allowing introduction of a small curved instrument into the joint space and creation of small holes in the subchondral bone at a perpendicular angle.[103] However, the technique is still in its infancy and needs further development before it can be applied in clinical practice.

Although debridement and bone marrow stimulation is considered the surgical treatment of choice, there are concerns that the fibrocartilage repair tissue has insufficient durability in the long term.[229,262] The primary aim of chapter 6 was to assess the long-term clinical and radiographic outcomes of arthroscopic debridement and bone marrow stimulation for talar OCDs. Fifty patients were evaluated after a mean follow-up of 12 years (range, 8 – 20 years). The outcomes suggested that the initial success rates of arthroscopic debridement and bone marrow stimulation for OCDs of the talus last over

time. This finding strengthens the recommendations of the treatment guideline presented in part I of the thesis. Other studies that published mid-term to long-term outcomes demonstrated similar results. These studies reported success rates of 72% to 86% after a mean follow-up of 5 to 10 years.[30,44,77,128,346]

The secondary aim of chapter 6 was to determine prognostic factors that affect the long-term outcome. The study probably was not sufficiently powered to identify prognostic factors. Other studies that included more than 100 patients identified the defect size as an independent prognostic factor.[76,77,82] These studies found a cutoff value of 15 mm for the defect diameter or 150 mm^2 for the defect area. Larger defects posed a higher risk of poor clinical outcomes.[76,77,82]

Different methods of bone marrow stimulation can be used, i.e., drilling, abrasion, and microfracturing. The latter is used the most at present. Chapter 7 described a potential pitfall in the microfracturing technique. The microfracture procedure may create small osseous fragments upon retrieval of the microfracture awl. These fragments may stay behind in the joint and act as loose bodies. Although the described pitfall could possibly influence patient outcome, this was not actually proven in the descriptive paper. Future studies, which specifically address the presence of bony particles with postoperative imaging after the microfracture procedure as well as the correlation with clinical outcome, may elucidate to what extent the particles are present and influence the clinical outcome.

Other issues related to the microfracturing technique that may require further optimization are the distance and depth of the microfracture holes. Most surgeons use intervals of 3 – 4 mm and penetrate the bone to such a depth that it leads to sufficient blood or fat droplets.[223] However, no data are available on which technique leads to the best outcome.[223] Further studies that compare different techniques will provide the evidence to answer these questions.

To accelerate the postoperative rehabilitation of OCDs, the advantageous effect of PEMF was postulated in chapter 2. The postoperative application of PEMF limited osteochondral graft resorption and cyst formation in sheep.[47] In vitro and in vivo studies showed that PEMF stimulation leads to an increase of transforming growth factor β, thereby improving bone development, reducing cartilage damage and increasing chondrocyte proliferation.[6,47,83,98] Clinical studies showed promising results for fracture nonunion and for recovery after arthroscopic treatment of focal cartilage knee lesions.[161,462] Therefore, PEMF stimulation may be effective for talar OCDs after arthroscopic treatment by producing effects that suppress inflammation, promote tissue healing, and relieve pain.[436]

Chapter 8 described the detailed study protocol of a prospective, double-blind, randomized, placebo-controlled multicenter trial. It was hypothesized that PEMF-treatment after arthroscopy leads to earlier resumption of sports and an increase in the number of patients to resume sports. Sixty-eight patients were randomized to either active PEMF-treatment or sham-treatment. The final follow-up of the last patient is expected in January 2014. The outcomes of the trial will be presented in future publications. A recent review of the literature identified numerous publications supporting the hypothesis.[132] The review concluded that the use of PEMF represents an innovative therapeutic approach, because this physical stimulus increases the anabolic activity of chondrocytes and cartilage explants with consequent increase of matrix synthesis. At the same time, PEMFs limit the catabolic effects of inflammatory cytokines.[132]

Part III – Secondary surgical treatment with a metal resurfacing inlay implant

If the primary arthroscopic treatment of a talar OCD fails, there are various alternative treatment methods. As described in part I, current secondary methods can be successful but have several disadvantages, one being donor-site morbidity. A metal resurfacing inlay implant was developed for the treatment of secondary, localized OCDs of the medial talar dome. It has a standard diameter of 15 mm and a variety of 15 incremental offset sizes. A preliminary assessment ascertained the safety, biocompatibility, and functionality of a similar metal implant in the goat knee.[216] Chapter 9 described a cadaveric study to test the following hypotheses: (1) a matching offset size is available for each talus, (2) the prosthetic device can be reproducibly implanted slightly recessed in relation to the talar cartilage level, and (3) with this implantation level, excessive contact pressures on the opposing tibial cartilage are avoided. The results suggested that the implant can be applied clinically in a safe way, with appropriate offset sizes for various talar domes, and without excessive pressure on the opposing cartilage.

A similar study was published 1 day after the study of chapter 9.[17] This study investigated the effect of implantation accuracy on ankle contact mechanics. Different implantation levels (-0.5 to 0.5 mm) were tested in seven ankle specimens. Contact stresses in the talocrural joint were measured with the specimen axially loaded to 300 N. The effects of rotation and angulation of the implant were tested in a finite element analysis. This study concluded that focal resurfacing with a metal implant has the potential to restore joint mechanics in ankles with a large OCD. A recessed to flush implantation height most closely restored the original contact stress distribution. Thus, in that study, flush implantation was also found adequate, perhaps because the specimens were loaded for a shorter duration and with lower compression forces than in chapter 9. The question is whether the load-bearing capacity of the focal resurfacing implant is required. A previous study tested the consequence of increasing talar defect area on contact characteristics of the talocrural joint. This study demonstrated significant changes for lesions larger than 15 mm (i.e., decreased total contact area and increased mean pressure), but not for smaller lesions.[80] Because the metal implant is 15 mm in diameter, recessed implantation may not be harmful to the remainder of the ankle joint, even if it is placed so deep that is does not carry any load. A recessed implant reduces the chance of overloading and damaging the opposing cartilage surface.

After the preliminary cadaveric study, the study described in chapter 10 evaluated the clinical effectiveness of the implant after failed prior surgical treatment. Twenty consecutive patients were prospectively studied. Based on a statistically significant improvement in most outcome measures, it was concluded that the metal implantation technique is a promising treatment for OCDs of the medial talar dome after failed previous treatment. These results were equaled by others. Ebskov presented similar outcomes at the 2013 annual meeting of the Danish foot and ankle society. The limitations of both studies were the relatively small series, lack of long-term follow-up, and absence of a control group. A limitation of the implant itself is the fixed diameter. In defects smaller than the implant, some healthy cartilage is sacrificed for implantation. In contrast, if the OCD is larger than the implant, some parts of the defect cannot be covered. The future development of different sizes may overcome this limitation. Furthermore, the implant was designed specifically for the medial talar dome. An implant for the lateral dome is focus of future research.

At the moment, the results of the metal resurfacing inlay implant compare with those of other resurfacing techniques such as OATS and allograft transplantation. Hangody et al. published the largest series of OATS in the talus.[178] The authors reported that 93% of 98 patients had good to excellent clinical results on the basis of evaluation with the Hannover score, but the duration of follow-up was not reported. The main disadvantage of OATS is the donor-site morbidity, which has been reported to occur in up to 50% of cases.[312,327,407] Allograft transplantation has gained increased attention as an alternative for large OCDs in the United States. El-Rashidy et al. and Haene et al. reported satisfactory outcomes after a mean follow-up of 3 to 4 years.[118,168] However, based on the available evidence, allografts are not recommended for focal defects because of the loss of viability and stability in approximately one-third of the grafts.[118,162,168]

A disadvantage of treatments such as the metal implantation, OATS, and allograft techniques is the necessity to perform a medial malleolar osteotomy for adequate exposure and perpendicular access to the medial talar dome. An inappropriate osteotomy technique may result in a damaged weight-bearing tibial plafond, insufficient access, or in malreduction, which may negatively affect the clinical outcome.[143,215] The studies in chapters 11 and 12 aimed to optimize the osteotomy technique.

To obtain a congruent joint surface after refixation, the oblique osteotomy should be directed perpendicularly to the articular surface of the tibia at the intersection between the tibial plafond and medial malleolus. The purpose of chapter 11 was to determine this direction in relation to the longitudinal tibial axis for use during surgery. Forty-six radiographs and CT scans were measured. A medial malleolar osteotomy was found to be perpendicular to the tibial articular surface when directed at a mean 30° relative to the tibial axis in the frontal plane. This direction likely results in maximum congruity of the joint surface after reduction of the osteotomy. The intraobserver and interobserver reliability of the measurements were good to excellent. Hence, the methods used in this study allow for the preoperative planning of the individual patient, for example in case of abnormal anatomy. The osteotomy angle is rarely reported in the literature. Some surgeons suggested an angle of 45° relative to the tibial plafond.[143,281,350] This is more horizontal than the direction found in our study. The 30° angle we found was subsequently used by others as a reference standard in the evaluation of their technique.[237]

Since it is difficult to visualize the intersection between the tibial plafond and medial malleolus (especially posterior) during surgery, chapter 12 described the use of a right-angled aiming probe, which is normally used for arthroscopic surgery, to identify both the posterior and anterior parts of the intersection, in order to perform a precise osteotomy. Others have used fluoroscopy to help identify the intersection, but this involves radiation and is more time-consuming.[308]

The angle and the probe, described in chapters 11 and 12, were applied during surgery and have subjectively improved the technique. However, clinical studies are required to determine if the techniques improve patient outcome. A next step in the refinement of the medial malleolar osteotomy could be the development of an intraoperative aiming device in which the use of probes and the angle are incorporated.

Part IV – Alternative treatment

Animal studies play an important role in the development of a new treatments prior to introduction in clinical practice. Numerous experimental studies focused on cartilage

defects of the knee,[81] but an experimental animal model of OCDs in the ankle joint was not available. We therefore developed such a model for talar OCDs in goats. The aim of chapter 13 was to test the developed animal model in vivo with use of autologous cancellous bone and donor DBM. It was possible to create a standardized 6-mm defect in each talus through a posterolateral surgical approach. After 12 weeks of healing, the analyses showed that most bony tissue was generated in the defects filled with autologous bone and least in the control defects. Our findings showed that a standard OCD can be created in the talus by a relatively simple procedure in a large animal that allows qualitative and quantitative evaluation. Various 2- and 3-dimensional parameters could be quantified in different regions with the combination of histomorphometry and μCT. No conclusions could be drawn on the effectiveness of the investigated materials because of the small number of goats.

Only few studies described the surgical exposure of an animal's ankle joint.[41,104,361] All studies used a posteromedial approach to the ankle of dogs, exposing 36% to 59% of the talar trochlea.[41,104] With this approach, a medial malleolar osteotomy was sometimes required to gain sufficient exposure.[361] Beale and Goring additionally described an anteromedial approach, exposing 43% to 64% of the medial talar trochlear ridge.[41] Prior to the study presented in chapter 13, four surgical approaches (anteromedial, anterolateral, posteromedial, and posterolateral) were evaluated on goat cadaver ankles. The posterolateral approach was found to be the most appropriate because of the excellent exposure of the talar dome and protection of neurovascular structures.

In published studies, various artificial defect sizes have been applied.[8,81] A critical size defect does not heal without treatment.[8] In the presented ankle model, the defects were sized 6 mm in diameter and depth. A goat study investigating the natural course of knee defects showed that 6-mm defects do not heal spontaneously within 1 year but rather develop into cystic lesions.[198] In the present model the control defects did not heal either, confirming that the created defect in the talus was appropriate.

Some points for improvement of the model were encountered. There was variation in outcome between the animals. The radiographs were useless for analysis of repair because the OCDs were not consistently visible. The fluorochrome labels were not always detectable in the histologic sections. The duration of follow-up was possibly too short for full remodeling of the defects, as evidenced by areas with osteoid and osteoblasts. It was concluded that the model, with a few adjustments such as a paired analysis and longer follow-up, can be used in future experiments investigating alternative treatment methods for talar OCDs.

DBM and platelet-rich plasma (PRP) possess the possibility of a one-step, minimally invasive procedure that stimulates biologic repair. Previous studies showed the effectiveness of DBM, e.g., in ankle fusion, tibial defects, and OCDs of rabbit knees.[140,171,391] Platelet-rich plasma (PRP) contains growth factors that could possibly enhance the treatment effect of DBM.[362] The purpose of chapter 14 was to evaluate the effectiveness of DBM with and without PRP in the treatment of 32 OCDs with use of the previously developed caprine model. In contrast to our hypotheses, none of the analyses revealed statistically significant differences between the groups after 24 weeks.

The absence of a positive effect may be caused by various factors. The effectiveness of DBM is dependent on donor age, processing technique, and sterilization procedure.[171,347,450,459] The DBM used in chapter 14, however, has proven osteoinductive and osteoconductive properties.[173,317,318] Although the use of DBM has resulted in advantageous outcomes for

nonunions and segmental defects of cysts of long bones,[107,117,145,171,392] the literature for intra-articular pathology is scarce.[94,140] Perhaps the joint environment precludes the proper healing response of DBM by the ingress of fluid into the repaired area.[433]

PRP is a promising (adjuvant) treatment for OCDs.[226,362] Multiple in vitro and in vivo studies delineate the potential of PRP to improve OCD repair.[362] The in vitro literature indicates that this biological adjunct may increase chondrocyte proliferation as well as synthetic capability, while limiting the catabolic effects of an inflammatory joint environment.[10,233,287,418] In a rabbit model, the addition of PRP showed improved healing of OCDs treated with microfracture surgery.[284] Human studies have reported variable effects of PRP injections alone as well as in addition to surgery. Not all studies concluded that PRP had a positive effect on cartilage repair.[226,363] The vast majority of studies investigated the knee. Extrapolation to the ankle joint is unreliable because of the differences in cartilage properties, joint congruence, and response to injury.[26,181,234,311] One study specifically investigated PRP for talar OCDs.[280] Thirty patients received three weekly intra-articular injections of hyaluronic acid or PRP. After 28 weeks of follow-up, the outcomes were significantly better for the PRP group in controlling pain and re-establishing function.[280] However, the aspect of the repair tissue was not investigated. The specimens in our animal study showed no improvement in healing of the tissue. Perhaps the combination of PRP and DBM is suboptimal, as their interaction is not yet well understood.[324] Furthermore, the concentration of PRP varied among the goats, but no significant differences in outcomes were found between high and low concentrations. Further studies are indicated to determine the ideal preparation of DBM and the optimal concentration of PRP as well as their interaction before they can be uniformly investigated.

Part V – Outcome measures

Outcome assessment is critical in evaluating the efficacy of orthopaedic procedures. Many outcome scores have been used to assess the effect of interventions for OCDs. Chapter 15 discussed frequently used clinical outcome scores and postoperative imaging studies. Some clear recommendations for the use of outcome scores were provided. However, it was stressed that none of the clinical outcome scores has been investigated psychometrically in the specific patient population with a talar OCD. There is a need for reliable and valid outcome measures that have been investigated in the target population and are available in different languages.

The Foot and Ankle Outcome Score (FAOS), as used in chapter 10, is one of the few validated outcome measures for ankle pathology. The score was available in Dutch and other languages but not in German. For the purpose of conducting clinical studies in Germany, a translation and validation study of the German FAOS was performed. This study was presented in chapter 16. After forward and backward translation, the final translation of the FAOS was validated in a series of 150 German patients with chronic foot and ankle-related problems. The findings indicated that the translated German version of the FAOS is a reliable and valid instrument for use in foot and ankle patients. Although the German version of the FAOS was not used in the clinical study investigating the metal implant (chapter 10), the results of chapter 16 enables its use in future international multicenter studies and allows for the comparison of studies from different countries. Translating and validating the FAOS into more languages as well as determining the minimal clinically important change will further expand its applicability.

Conclusions and future directions

The treatment of talar OCDs provides a challenge for the orthopaedic surgeon. In the recent past, there was discussion in the orthopaedic community on the optimal treatment plan. Although bone marrow stimulation had been applied for a long time and was considered the primary treatment, surgeons questioned the durability of the fibrocartilaginous repair tissue.[229,262] Furthermore, it was sometimes unclear which surgical approach to the OCD was most appropriate. Previous secondary treatments had disadvantages such as morbidity of the donor site and limited availability. To investigate alternatives, only knee animal models were available. Lastly, a great diversity of outcome measures was available to report clinical results of talar OCD treatment. The choice for the outcome measure used seemed arbitrary.

This thesis has contributed to the treatment of patients with talar OCDs in various ways. The literature was reviewed and a treatment algorithm was proposed. The long-term outcomes of arthroscopic bone marrow stimulation reassured the durability of the technique and set the reference standard for other procedures to equal. Evidence-based directions for preoperative planning by CT scanning were provided. CT scans showed that almost half of the talar dome is accessible in the anterior working area with the ankle in full plantar flexion. The trial on acceleration of the rehabilitation with PEMF is only months before final follow-up. A novel metal implantation technique was prospectively investigated. Most patients had good clinical outcomes at a mean follow-up of 3 years. The implant can be considered a valuable alternative to current secondary treatment methods. The open surgical approach with use of the medial malleolar osteotomy was refined. When directed at a mean 30° angle relative to the long tibial axis, the osteotomy enters the joint perpendicularly to the tibial cartilage at the intersection with the medial malleolus. A goat model was developed for the ankle joint, which allows reproducible creation of a talar OCD and qualitative and quantitative analysis. DBM and PRP were investigated with use of the developed goat model. They were not effective in the treatment of goat OCDs compared to control defects. Finally, various outcome measures were reviewed, and a guideline was provided. The German version of the FAOS was translated and validated.

Several recommendations can be made for treatment of talar OCDs on the basis of the thesis and the current literature. Based on the long-term outcomes, arthroscopic bone marrow stimulation remains the primary surgical treatment for chronic OCDs up to 15 mm. If the primary treatment fails, various secondary treatment options remain, including OATS, (matrix-induced) ACI, cancellous bone grafting, and metal resurfacing. The choice depends on patient and lesion characteristics as well as surgeon preferences. Any malalignment of the hindfoot should probably be corrected concomitantly. Salvage procedures for refractory defects are allograft transplantation, ankle arthrodesis and total arthroplasty.

Despite the advancements achieved by the studies reported in this thesis, there is an ongoing debate among orthopaedic surgeons. There are still many possibilities for future research to further ameliorate the perspective of patients with a talar OCD. Arthroscopic bone marrow stimulation has been proven to be effective over the years. Future research may further increase the success rate of the technique. The outcomes of bone marrow stimulation may be improved by identifying the most effective depth and distance of subchondral bone penetration. Additionally, in cases where the OCD is difficult to reach, the development of new techniques and instruments may assist the surgeon in

treating the OCD adequately with minimal soft-tissue damage. The use of pressurized water jets is a promising development in this area.[103] The presence of postoperative bony particles after the microfracture procedure should be identified with postoperative imaging techniques to determine to what extent the particles are present and whether clinical outcome is affected. The metal resurfacing inlay implant was found to be a promising option for the treatment of secondary OCDs of the medial talar dome. However, more patients, longer follow-up, and a control group will better determine the place of the implant in the treatment of talar OCDs. The development of additional implant sizes as well as an implant for the lateral talar dome will expand its use. Correction osteotomy for OCDs in malaligned ankles seems a promising solution but clinical studies are required. Cell-based (adjunct) therapies may become more attractive in the future.[362] PRP was not beneficial in the study described in chapter 14, but its use was promising in other studies.[226,363] Determining the optimal concentration and application is important before the clinical effect of PRP can be evaluated reliably. An alternative cell-based therapy is bone marrow aspirate concentrate, but clinical data are scarce.[150,214,362] The ultimate goal of OCD treatment is to regenerate the complete osteochondral unit by a construct that results in repair of the subchondral bone as well as an integrated layer of hyaline cartilage. However, inferior methods will have to be used until such an ideal treatment is available.

In the current era of evidence based medicine, there is still no optimal treatment for talar OCDs. Great diversity and variability between studies provide the surgeon interesting choices with an important role for the patient and his or her demands. Sufficiently powered, randomized controlled trials with uniform methodology and validated outcome measures, as well as the optimization of current treatment methods and development of new methods, may form the foundation of the optimal treatment plan for future talar OCDs.

Summary

Chapter 1
General introduction

An osteochondral defect (OCD) involves the articular cartilage and its subchondral bone. Symptomatic OCDs of the talus most frequently appear in the second and third decade of life. A traumatic insult, usually ankle sprain, is the most frequent etiologic factor. The typical symptom of a chronic lesion is persistent or intermittent deep ankle pain during or after activity. Plain radiographs may disclose the lesion. For further diagnostic evaluation, computed tomography (CT) and magnetic resonance imaging (MRI) have demonstrated similar accuracy. CT scanning is preferred for preoperative planning because it better visualizes the bony defect. The integrity of the subchondral bone seems crucial in the development and the treatment of OCDs. There are numerous treatment methods. The general aim of this thesis was to improve the outcome for the patient by optimizing arthroscopic treatment and evaluating alternative treatment. The specific aims were to review and summarize the literature, evaluate primary arthroscopic treatment, improve preoperative planning, accelerate aftertreatment, analyze a novel metal resurfacing inlay implant, develop an animal model specifically for talar OCDs, investigate the effect of demineralized bone matrix and platelet-rich plasma, and improve the reporting of outcomes.

Part I – Current concepts

Chapter 2
Treatment of osteochondral defects of the talus

Current concepts of treatment types, their indications, and future developments in treatment were reviewed. Based on the results presented in the literature, a treatment algorithm was presented that was mainly guided by the size of the lesion. In the algorithm, asymptomatic or low-symptomatic lesions are treated nonoperatively. The primary surgical treatment of defects up to 15 mm in diameter consists of arthroscopic debridement and bone marrow stimulation. Retrograde drilling combined with a bone graft is an alternative for large cystic talar lesions. Fixation of the fragment is preferred in adolescents or in (sub)acute situations in which the fragment is 15 mm or larger. Osteochondral autograft transfer and autologous chondrocyte implantation, with or without a cancellous bone graft, were recommended for secondary cases as well as large lesions.

Chapter 3
Advancements in ankle arthroscopy

Ankle arthroscopy has gradually changed from a diagnostic to a therapeutic tool during the past 30 years. Most arthroscopic procedures can be performed by using the anterior working area with the ankle in dorsiflexion or plantar flexion; there is no need for routine ankle distraction. Anterior ankle problems, such as the anterior impingement syndrome, are approached by anteromedial and anterolateral portals and, if necessary, an accessory portal. Most OCDs can be reached from anterior with the ankle in plantar flexion. For a far posterior location, the OCD can be approached from posterior. The two-portal hindfoot endoscopic technique (i.e., both arthroscopic and endoscopic surgery), with the patient in the prone position, provides excellent access to the posterior ankle compartment and to posteriorly located extra-articular structures.

Part II – Primary arthroscopic debridement and bone marrow stimulation

Chapter 4
Computed tomography of the ankle in full plantar flexion: a reliable method for preoperative planning of arthroscopic access to osteochondral defects of the talus

The purpose of chapter 4 was to assess whether a preoperative CT of the ankle joint in full plantar flexion is a reliable and accurate tool to determine the anterior arthroscopic accessibility of talar OCDs. Twenty consecutive patients were prospectively studied. All patients had an OCD of the talar dome and had a preoperative CT scan of the affected ankle in maximum plantar flexion in a metal-free 3-dimensional footplate. Accessibility of the OCD was defined by the distance between the anterior border of the OCD and the anterior distal tibial rim. Two investigators measured this distance on sagittal CT reconstructions. The reference standard was the distance between the same landmarks measured during anterior ankle arthroscopy by an orthopaedic surgeon blinded to the CT scans. Intraobserver and interobserver reliability of CT, as well as the correlation and agreement between CT and arthroscopy, were calculated. The measured distance between the anterior border of the OCD and the anterior distal tibial rim ranged from -3.1 to 9.1 mm on CT and from -3.0 to 8.5 mm on arthroscopy. The intraobserver and interobserver reliability of the measurements made on CT scans (intraclass correlation coefficients [ICC] >0.99; p <0.001), as well as the correlation between CT and arthroscopy (r = 0.98; p <0.001), were excellent. This study showed that measurements on CT scans of the ankle in full plantar flexion are a reliable and accurate preoperative method to determine the in situ arthroscopic location of talar OCDs.

Chapter 5
Arthroscopic accessibility of the talus quantified by computed tomography simulation

The dual purpose of this chapter was (1) to quantify the anterior arthroscopic reach of the talus (i.e., proportion of the talar dome anterior to the anterior distal tibial rim) with the ankle in full plantar flexion, and (2) to identify predictive factors of the arthroscopic reach. CT scans were obtained of 59 ankles in full plantar flexion in the 3-dimensional footplate. The arthroscopic reach of both the medial and lateral talar domes was assessed on sagittal reconstructions using a custom-made software routine. Intraobserver and interobserver reliability were calculated by ICCs. Various predictive factors of the arthroscopic reach were analyzed by multivariate linear regression analysis. The arthroscopic reach was 48.2% ± 6.7% (range, 26.7% - 60.7%) of the medial talar dome and 47.8% ± 6.5% (range, 31.2% - 65.1%) of the lateral talar dome (p = 0.62). The intraobserver and interobserver reliability of both measurements were excellent (ICC, 0.99). The clinical plantarflexion angle was a statistically significant predictive factor of both the medial and lateral arthroscopic reaches (i.e., increased plantar flexion corresponded to increased area of access), while joint laxity, gender, and age were not predictive. The following conclusions could be drawn: (1) almost half of the talar dome is accessible anterior to the anterior distal tibial rim, and (2) the plantarflexion angle is an independent predictive factor of the arthroscopic reach both medially and laterally.

Chapter 6
Arthroscopic treatment for osteochondral defects of the talus: outcomes after 8 to 20 years of follow-up

The primary aim of chapter 6 was to assess the long-term clinical and radiographic outcomes of arthroscopic debridement and bone marrow stimulation for talar OCDs. The secondary aim was to identify prognostic factors that affect the long-term results. Fifty (88%) of 57 eligible patients with a primary OCD treated with arthroscopic debridement and bone marrow stimulation were evaluated after a mean follow-up of 12 years (range, 8 – 20 years). Clinical assessment included the Ogilvie-Harris score, Berndt and Harty outcome question, American Orthopaedic Foot & Ankle Society (AOFAS) ankle-hindfoot score, and Short Form-36 (SF-36) as well as resumption of work and sports. Weight-bearing radiographs were compared with preoperative radiographs with use of an ankle osteoarthritis classification.[425] Various possible prognostic factors were recorded and analyzed with use of univariate logistic regression, including the size, location, and classification of the defect, patient age and body mass index, traumatic etiology, and duration of symptoms. The Ogilvie-Harris score was excellent in 20% of patients, good in 58%, fair in 22%, and poor in 0%. According to the Berndt and Harty outcome question, 74% of patients rated the ankle as good, 20% as fair, and 6% as poor. The median AOFAS score was 88 (range, 64 – 100). Of the eight subscales of the SF-36, six were comparable with population norms and two were superior in the study group. Ninety-four percent of patients had resumed work and 88% had resumed sports. The radiographs indicated an osteoarthritis grade of 0 in 33% of the patients, I in 63%, II in 4%, and III in 0%. Compared with the preoperative osteoarthritis classification, 67% of radiographs showed no progression and 33% showed progression by one grade. None of the prognostic factors was significantly associated with the Ogilvie-Harris score or progression of osteoarthritis. This study suggested that initial success rates of arthroscopic debridement and bone marrow stimulation for OCDs of the talus are maintained over time. No factors that were predictive of the outcome could be identified.

Chapter 7
Potential pitfall in the microfracturing technique during the arthroscopic treatment of an osteochondral lesion

The microfracture procedure may create small osseous fragments upon retrieval of the microfracture awl, which may stay behind in the joint and act as loose bodies. It was emphasized that the joint should be carefully inspected and flushed at the end of each procedure.

Chapter 8
Pulsed electromagnetic fields after arthroscopic treatment for osteochondral defects of the talus: double-blind randomized controlled multicenter trial

In chapter 8, the detailed study protocol was described of a prospective, double-blind, randomized, placebo-controlled multicenter trial conducted in five centers in the Netherlands and Belgium. We hypothesized that pulsed electromagnetic field (PEMF) treatment compared to sham-treatment after arthroscopy leads to earlier resumption of sports, and aimed at 25% increase in patients that resumed sports. Sixty-eight patients were randomized to either active PEMF-treatment or sham-treatment for 60 days, 4 h daily. The primary outcome measures were (a) the percentage of patients that resumed and maintained sports, and (b) the time to resumption of sports, defined by the Ankle Activity Score. Secondary outcome measures included resumption of work, subjective and objective

scoring systems (AOFAS score, Foot and Ankle Outcome Score [FAOS], numeric rating scales of pain and satisfaction, and EuroQol-5D), and CT. This trial will provide level-1 evidence on the effectiveness of PEMF in the management of osteochondral ankle lesions after arthroscopy.

Part III – Secondary surgical treatment with a metal resurfacing inlay implant

Chapter 9
Novel metallic implantation technique for osteochondral defects of the talus: a cadaver study

A metal resurfacing inlay implant with 15 offset sizes was developed for the treatment of localized OCDs of the medial talar dome. The aim of chapter 9 was to test the following hypotheses: (1) a matching offset size is available for each talus, (2) the prosthetic device can be reproducibly implanted slightly recessed in relation to the talar cartilage level, and (3) with this implantation level, excessive contact pressures on the opposite tibial cartilage are avoided. The prosthetic device was implanted in 11 intact fresh-frozen human cadaver ankles, aiming its surface 0.5 mm below cartilage level. The implantation level was measured at four edges of each implant. Intra-articular contact pressures were measured before and after implantation, with compressive forces of 1,000 - 2,000 N and the ankle joint in plantigrade position, 10˚ of dorsiflexion, and 14˚ of plantar flexion. There was a matching offset size available for each specimen. The mean implantation level was 0.45 ± 0.18 mm below cartilage surface. The defect area accounted for a median of 3% (range, 0.02% – 18%) of the total ankle contact pressure before implantation. This was reduced to 0.1% (range, 0.02% – 13%) after prosthetic implantation. These results suggested that the implant can be applied clinically in a safe way, with appropriate offset sizes for various talar domes and without excessive pressure on the opposite cartilage.

Chapter 10
Treatment of secondary osteochondral defects of the talus with a metal resurfacing inlay implant: a prospective study

The aim of chapter 10 was to evaluate the clinical effectiveness of the metal resurfacing inlay implant for OCDs of the medial talar dome after failed prior surgical treatment. Twenty consecutive patients, aged 20 to 60 years (mean, 38 years), were prospectively studied for 2 to 5 years (mean, 3 years). There was statistically significant reduction of pain in each of four situations (i.e., rest, walking, stair climbing, and running; $p \leq 0.01$). The median AOFAS score improved from 62 (range, 28 – 75) preoperatively to 87 (range, 42 – 100) at final follow-up ($p < 0.01$). The FAOS improved on all subscales ($p \leq 0.03$). The mean SF-36 physical component scale improved from 36 ± 8.2 preoperatively to 45 ± 7.8 at final follow-up ($p < 0.01$); the mental component scale did not change significantly. On radiographs, progressive degenerative changes of the opposing tibial plafond were observed in two patients. One patient required additional surgery for the OCD. This study showed that the metal implantation technique is a promising treatment for OCDs of the medial talar dome after failed previous treatment.

Chapter 11
Direction of the oblique medial malleolar osteotomy for exposure of the talus.

A medial malleolar osteotomy is often indicated for operative exposure of posteromedial OCDs and fractures of the talus. To obtain a congruent joint surface after refixation, the oblique

osteotomy should be directed perpendicularly to the articular surface of the tibia at the intersection between the tibial plafond and medial malleolus. The purpose of chapter 11 was to determine this direction in relation to the longitudinal tibial axis for use during surgery. Using anteroposterior mortise radiographs and coronal CT scans of 46 ankles (45 patients) with an OCD of the talus, two observers independently measured the intersection angle between the tibial plafond and the medial malleolus. The bisector of this angle indicated the osteotomy perpendicular to the tibial articular surface. This osteotomy was measured relative to the longitudinal tibial axis on radiographs. ICCs were calculated to assess reliability. The mean osteotomy was 57.2° ± 3.2° relative to the tibial plafond on radiographs and 56.5° ± 2.8° on CT scans. This osteotomy corresponded to 30.4° ± 3.7° relative to the longitudinal tibial axis. The intraobserver (ICC, 0.90 - 0.93) and interobserver (ICC, 0.65 - 0.91) reliability of these measurements were good to excellent. It was concluded that a medial malleolar osteotomy directed at a mean 30° relative to the tibial axis enters the joint perpendicularly to the tibial cartilage, and will likely result in a congruent joint surface after reduction.

Chapter 12
Clinical tip: aiming probe for a precise medial malleolar osteotomy

The use of a right-angled aiming probe was described to identify both the posterior and anterior parts of the intersection between the tibial plafond and medial malleolus, in order to perform a precise medial malleolar osteotomy.

Part IV – Alternative treatment

Chapter 13
Osteochondral defects of the talus: a novel animal model in the goat

An experimental animal model of the ankle joint was not available. The aim of chapter 13 was to test a newly developed animal model for OCDs of the ankle in vivo. OCDs were created in the talus of goat hind legs using a posterolateral surgical approach. The defects were filled with either autologous cancellous bone or donor demineralized bone matrix (DBM) or left empty as control. After 12 weeks of healing, the specimens were analyzed with radiography, macroscopy, μCT, histology, histomorphometry, and fluorescence microscopy. It was possible to create a standardized defect in each talus. The implanted material remained in place. The analyses showed that most bony tissue was generated in the defects filled with autologous bone and least in the control defects. Our findings showed that a standard OCD can be created in the talus by a relatively simple procedure in a large animal that allows qualitative and quantitative evaluation. It was concluded that the model can be used in future experiments to investigate alternative treatment methods before they are introduced into clinical practice.

Chapter 14
Demineralized bone matrix and platelet-rich plasma for osteochondral defects of the talus: an experimental goat study

The purpose of chapter 14 was to evaluate the effectiveness of DBM with and without platelet-rich plasma (PRP) in the treatment of OCDs of talus. We hypothesized that treatment with DBM would result in more bone formation than no treatment in control OCDs, and that PRP would further enhance the regenerative capacity of DBM. A standardized 6-mm OCD was

created in each talus of 16 adult goats. According to a randomization scheme, one OCD of each goat was treated with allogeneic DBM hydrated with normal saline (n = 8) or hydrated with autologous PRP (n = 8). The contralateral OCD (n = 16) served as control. After 24 weeks, the animals were euthanized and the tali excised. Various outcome parameters were analyzed with use of macroscopic evaluation, μCT, histology, histomorphometry, and fluorescence microscopy. None of the analyses revealed statistically significant differences between the groups for any of the parameters analyzed in any volume of interest. For example, the mean bone volume fraction of the defect, as measured by μCT, was 0.56 ± 0.17 for DBM hydrated with normal saline and 0.52 ± 0.18 for DBM hydrated with PRP, compared to 0.53 ± 0.12 and 0.54 ± 0.14 for the internal controls, respectively ($p > 0.05$). In contrast to our hypotheses, no beneficial treatment effect of DBM with or without PRP was found for OCDs of the caprine talus.

Part V – Outcome measures

Chapter 15
Outcome measures

Outcome assessment is critical in evaluating the efficacy of orthopaedic procedures. Frequently used clinical outcome scores for talar OCDs were discussed in chapter 15. In addition, the chapter discussed scoring systems based on postoperative imaging. The following conclusions were drawn: (1) the AOFAS score is a frequently used outcome measure for talar OCD, but has some limitations, (2) the FAOS and the Foot and Ankle Ability Measure are functional patient-reported outcome scores that are useful in the clinical assessment of patients with a talar OCD, (3) the 11-point numeric rating scale is a suitable, valid, and practical scale to assess pain intensity, and (4) postoperative imaging can be used for objective assessment of repair tissue.

Chapter 16
Translation and validation of the German Foot and Ankle Outcome Score

The FAOS is a 42-item questionnaire divided into five subscales, which has been validated in several languages. Germany had no validated outcome score for general foot and ankle pathology. The aim of this study was to develop a German version of the FAOS and to investigate its psychometric properties. Forward and backward translations were executed according to official guidelines. The final version of the FAOS was investigated in 150 patients with various foot and ankle disorders. All patients completed the FAOS, SF-36, numeric rating scales for pain and disability, and the Hannover questionnaire. The FAOS was re-administered after one week. Test-retest reliability, internal consistency, minimal detectable change, construct validity, and floor and ceiling effects were analyzed.

Test-retest reliability and internal consistency of each subscale were excellent (ICC, 0.88 - 0.95; Cronbach's alpha, 0.94 - 0.98). The minimal detectable changes of each subscale were 17.1 to 20.8 at the individual level and 2.0 to 2.4 at group level. There were moderate to strong correlations between FAOS subscales and physical outcomes and low to moderate correlations between FAOS subscales and mental outcomes. Floor and ceiling effects were not present. These outcomes indicated that the German version of the FAOS is a reliable and valid instrument for use in foot and ankle patients.

General discussion and summary

Chapter 17
General discussion

The treatment of talar OCDs provides a challenge for the orthopaedic surgeon. This thesis has contributed to the treatment of patients with talar OCDs in various ways. The literature was reviewed and a treatment algorithm was proposed. The long-term outcomes of arthroscopic bone marrow stimulation reassured the durability of the technique and set the reference standard for other procedures to equal. CT scans showed that almost half of the talar dome is accessible in the anterior working area with the ankle in full plantar flexion. The trial on acceleration of the rehabilitation with PEMF is only months before final follow-up. A novel metal implantation technique led to good clinical outcomes in most patients at a mean follow-up of 3 years. A medial malleolar osteotomy for exposure of the talus enters the joint perpendicularly to the tibial cartilage at the intersection with the medial malleolus when directed at a mean 30° angle relative to the long tibial axis. DBM and PRP were investigated with use of a newly developed goat model. They were not effective in the treatment of goat OCDs compared to control defects. Finally, various outcome measures were reviewed, and a guideline for their use was provided. The German version of the FAOS was translated and validated.

Several recommendations can be made for treatment of talar OCDs on the basis of the thesis and the current literature. Arthroscopic bone marrow stimulation remains the primary surgical treatment for chronic OCDs up to 15 mm. If the primary treatment fails, various secondary treatment options remain, including OATS, (matrix-induced) ACI, cancellous bone grafting, and metal resurfacing. The choice depends on patient and lesion characteristics as well as surgeon preferences.

There are still many possibilities for future research to further ameliorate the perspective of patients with a talar OCD. Future research should focus on improving the bone marrow stimulation technique, for example, by identifying the most effective depth and distance of subchondral bone penetration. The ultimate goal of OCD treatment is to regenerate the complete osteochondral unit by a construct that results in repair of the subchondral bone as well as an integrated layer of hyaline cartilage. However, inferior methods will have to be used until such an ideal treatment is available.

Great diversity and variability between studies provide the surgeon interesting choices with an important role for the patient and his or her demands. Sufficiently powered, randomized controlled trials with uniform methodology and validated outcome measures, as well as the optimization of current treatment methods and development of new methods, may form the foundation of the optimal treatment plan for future talar OCDs.

Nederlandse samenvatting

Hoofdstuk 1
Algemene inleiding

Bij een osteochondraal defect (OD) zijn het gewrichtskraakbeen en het onderliggende bot aangetast. Symptomatische OD's van de talus komen het meeste voor in de leeftijd van 20 tot 40 jaar. Een trauma, zoals enkeldistorsie, is de meest voorkomende oorzaak. Het typische symptoom van een chronische laesie is persisterende of intermitterende diepe enkelpijn tijdens of na belasten. Standaard röntgenfoto's kunnen de laesie aantonen. Voor verdere diagnostische evaluatie hebben computertomografie (CT) en magnetische resonantietechnieken (MRI) dezelfde nauwkeurigheid. Voor preoperatieve planning gaat de voorkeur uit naar CT, omdat het benige defect beter gevisualiseerd wordt. De integriteit van het subchondrale bot lijkt cruciaal in de ontwikkeling en behandeling van OD's. Er zijn diverse behandelmogelijkheden. Het algemene doel van dit proefschrift was het verbeteren van de uitkomst van de patiënt door middel van het optimaliseren van artroscopische behandeling en het evalueren van alternatieve behandelingen. De specifieke doelen waren het geven van een overzicht van de literatuur, evalueren van de primaire artroscopische behandeling, verbeteren van de preoperatieve planning, versnellen van de nabehandeling, analyseren van een nieuw metalen implantaat, ontwikkelen van een diermodel specifiek voor OD's van de talus, onderzoeken van het effect van gedemineraliseerde botmatrix en plaatjesrijk plasma en verbeteren van de rapportage van uitkomsten.

Deel I – Huidige inzichten

Hoofdstuk 2
Behandeling van osteochondrale defecten van de talus

Huidige inzichten van behandelmethoden, de indicaties en toekomstige ontwikkelingen werden besproken. Gebaseerd op de resultaten in de literatuur werd een behandelalgoritme gepresenteerd met als belangrijkste leidraad de afmeting van de laesie. In het algoritme worden asymptomatische en laagsymptomatische laesies niet-operatief behandeld. De primaire chirurgische behandeling van defecten tot 15 mm in diameter bestaat uit artroscopisch debridement en beenmergstimulatie. Retrograad opboren in combinatie met spongiosaplastiek is een belangrijk alternatief voor grote, cysteuze laesies. In adolescenten of in (sub-)acute situaties met een fragment van 15 mm of groter gaat de voorkeur uit naar fixatie van het fragment. Mozaïekplastiek en autologe chondrocyten implantatie, met of zonder spongiosaplastiek, werden aanbevolen voor secundaire casus en grote laesies.

Hoofdstuk 3
Ontwikkelingen in enkelartroscopie

Enkelartroscopie is geleidelijk veranderd van een diagnostisch naar een therapeutisch instrument gedurende de afgelopen 30 jaar. De meeste artroscopische procedures kunnen uitgevoerd worden door gebruik te maken van de anterieure werkruimte met de enkel in dorsaalflexie of plantairflexie. Het routinematig gebruiken van enkeldistractie is niet nodig. Voorste enkelproblemen, zoals anterieure impingement, worden benaderd door anteromediale en anterolaterale portals en zo nodig een additionele portal. De meeste OD's kunnen bereikt worden vanuit anterieur met de enkel in plantairflexie. Een achterin gelokaliseerd defect kan benaderd

worden via een posterieure enkelartroscopie. De posterieure scopietechniek, met twee portals en de patiënt in buikligging, geeft uitstekende toegang tot het achterste enkelcompartiment en tot posterieur gelegen extra-articulaire structuren.

Deel II – Primair artroscopisch debridement en beenmergstimulatie

Hoofdstuk 4
Computertomografie van de enkel in volledige plantairflexie: een betrouwbare methode voor preoperatieve planning van artroscopische toegang tot osteochondrale defecten van de talus

Het doel van hoofdstuk 4 was na te gaan of een preoperatieve CT van de enkel in volledige plantairflexie een betrouwbare en nauwkeurige methode is om de artroscopische bereikbaarheid van een OD te bepalen. 20 opeenvolgende patiënten met een OD van de talus werden prospectief bestudeerd. Bij alle patiënten werd een preoperatieve CT-scan van de aangedane enkel in maximale plantairflexie gemaakt in een niet-metalen 3-dimensionale voetplaat. De bereikbaarheid van het OD werd gedefinieerd als de afstand tussen de anterieure begrenzing van het defect en de voorrand van de distale tibia. Twee beoordelaars maten deze afstand op sagitale CT-reconstructies. De referentiestandaard was de afstand tussen dezelfde punten gemeten tijdens anterieure enkelartroscopie door een orthopedisch chirurg geblindeerd voor de CT-scans. De intra- en interobserver betrouwbaarheid van de CT-metingen, evenals de correlatie en overeenkomst tussen CT en artroscopie, werden berekend. De gemeten afstand tussen de anterieure begrenzing van het OD en de voorrand van de distale tibia varieerde van -3,1 tot 9,1 mm op CT en van -3,0 tot 8,5 mm bij artroscopie. De intra- en interobserver betrouwbaarheid van de metingen op CT (intraclass correlatie coëfficiënt [ICC] >0,99; p <0,001) en de correlatie tussen CT en artroscopie (r = 0,98; p <0,001) waren uitstekend. Deze studie liet zien dat metingen op CT-scans van de enkel in volledige plantairflexie een betrouwbare en nauwkeurige preoperatieve methode zijn om de in situ artroscopische lokalisatie van het OD te bepalen.

Hoofdstuk 5
Artroscopische bereikbaarheid van de talus gekwantificeerd met computertomografie simulatie

Het tweeledige doel van dit hoofdstuk was (1) het kwantificeren van het anterieure artroscopisch bereik van de talus (i.e. gedeelte van de talusrol anterieur van de voorrand van de distale tibia) met de enkel in volledige plantairflexie en (2) het identificeren van voorspellende factoren voor het artroscopisch bereik. CT-scans werden gemaakt van 59 enkels in volledige plantairflexie in de 3-dimensionale voetplaat. Het artroscopisch bereik van zowel de mediale als laterale talusrol werd gemeten op sagitale reconstructies met behulp van zelfgeprogrammeerde software. Intra- en interobserver betrouwbaarheid werden berekend met ICC's. Voorts werden verscheidene factoren die mogelijk voorspellend waren voor het artroscopisch bereik geanalyseerd door middel van multivariate lineaire regressie analyse. Het artroscopisch bereik was 48,2% ± 6,7% (range 26,7% - 60,7%) van de mediale talusrol en 47,8% ± 6,5% (range 31,2% - 65,1%) van de laterale talusrol. De intra- en interobserver betrouwbaarheid van beide metingen waren uitstekend (ICC 0,99). De klinische plantairflexiehoek was een statistisch significante voorspellende factor van het artroscopisch bereik van zowel de mediale als de laterale talusrol (i.e. een grotere hoek correspondeerde met een groter bereik), terwijl gewrichtslaxiteit,

geslacht en leeftijd niet voorspellend waren. De volgende conclusies konden worden getrokken: (1) bijna de helft van de talusrol is bereikbaar anterieur van de voorrand van de distale tibia en (2) de plantairflexiehoek is een onafhankelijke voorspellende factor van het artroscopisch bereik, zowel mediaal als lateraal.

Hoofdstuk 6
Artroscopische behandeling van osteochondrale defecten van de talus: uitkomsten na 8 tot 20 jaar follow-up

Het primaire doel van hoofdstuk 6 was het evalueren van de lange termijn klinische en radiologische uitkomsten van artroscopisch debridement en beenmergstimulatie voor OD's van de talus. Het secundaire doel was het identificeren van prognostische factoren die de lange termijn resultaten beïnvloeden. 50 (88%) van 57 patiënten met een primair OD, behandeld middels artroscopisch debridement en beenmergstimulatie, werden geëvalueerd na een gemiddelde follow-up van 12 jaar (range 8 – 20 jaar). De klinische uitkomstmaten waren de Ogilvie-Harris score, Berndt en Harty uitkomstvraag, American Orthopaedic Foot & Ankle Society (AOFAS) score en Short Form-36 (SF-36), evenals werk- en sporthervatting. Belaste röntgenfoto's werden vergeleken met preoperatieve röntgenfoto's met behulp van een artrose classificatie.[425] Verscheidene mogelijk prognostische factoren (zoals defectgrootte, -lokalisatie en -classificatie, leeftijd, body mass index, trauma en duur van de klachten voor de operatie) werden vastgelegd en geanalyseerd door middel van univariate logistische regressie. De Ogilvie-Harris score was uitstekend in 20% van de patiënten, goed in 58%, matig in 22% en slecht in 0%. Volgens de Berndt en Harty uitkomstvraag gradeerde 74% van de patiënten de enkel goed, 20% matig en 6% slecht. De mediane AOFAS score was 88 (range 64 – 100). Van de acht subschalen van de SF-36 waren zes vergelijkbaar met het populatiegemiddelde en waren twee beter in de studiegroep. 94% van de patiënten had het werk hervat en 88% de sport. De röntgenfoto's toonden artrose graad 0 in 33% van de patiënten, I in 63%, II in 4% en III en 0%. Vergeleken met de preoperatieve classificatie toonde 67% geen progressie van artrose en toonde 33% progressie van een graad. Geen van de vastgelegde factoren was significant geassocieerd met de Ogilvie-Harris score of met progressie van artrose. De resultaten van deze studie suggereerden dat de initiële succespercentages van artroscopisch debridement en beenmergstimulatie van OD's van de talus behouden blijven op de lange termijn. Prognostische factoren konden niet worden geïdentificeerd.

Hoofdstuk 7
Mogelijke valkuil van de microfracture techniek tijdens de artroscopische behandeling van een osteochondraal defect

Tijdens de microfracture procedure kunnen kleine benige fragmenten ontstaan bij het terugtrekken van de priem uit het bot, die kunnen achterblijven in het gewricht en leiden tot corpora libera. Het werd benadrukt dat het gewricht zorgvuldig geïnspecteerd en gespoeld moet worden aan het einde van iedere ingreep.

Hoofdstuk 8
Gepulseerde elektromagnetische velden na artroscopische behandeling van osteochondrale defecten van de talus: dubbelblind gerandomiseerde gecontroleerde multicenter studie

In hoofdstuk 8 werd het gedetailleerde studieprotocol beschreven van een prospectieve, dubbelblinde, gerandomiseerde, placebogecontroleerde multicenter studie, uitgevoerd in vijf centra in Nederland en België. Onze hypothese

was dat behandeling met gepulseerde elektromagnetische velden (PEMF), vergeleken met imitatie, tot eerdere sporthervatting zou leiden na artroscopie en we beoogden een verhoging van 25% van de patiënten die de sport hervatten. 68 patiënten werden gerandomiseerd voor actieve PEMF-behandeling of imitatie gedurende 60 dagen, 4 uur per dag. De gecombineerde primaire uitkomstmaat was (a) het percentage van de patiënten dat sport hervatte en behield en (b) de tijd tot sporthervatting, gedefinieerd met behulp van de Ankle Activity Score. Secundaire uitkomstmaten waren werkhervatting, subjectieve en objectieve scoringssystemen (AOFAS score, Foot en Ankle Outcome Score [FAOS], numerieke rating schalen van pijn en tevredenheid en EuroQol-5D) en CT. Deze studie zal bewijs van niveau 1 verschaffen over de effectiviteit van PEMF in de behandeling van OD's van de talus na artroscopie.

Deel III – Secundaire chirurgische behandeling met een metalen implantaat

Hoofdstuk 9
Nieuwe metalen implantatietechniek voor osteochondrale defecten van de talus: een kadaverstudie

Een metalen implantaat met 15 verschillende krommingsmaten was ontwikkeld voor de behandeling van OD's van de mediale talusrol. Het doel van hoofdstuk 9 was het testen van de volgende hypothesen: (1) er is een passende krommingsmaat beschikbaar voor iedere talus, (2) het implantaat kan reproduceerbaar iets verzonken ten opzichte van het omliggende kraakbeen worden geplaatst en (3) met dit implantatieniveau worden verhoogde contactdrukken op het tegenoverliggende tibiakraakbeen vermeden. Het implantaat werd in 11 intacte, versbevroren, humane kadaverenkels geïmplanteerd, waarbij het beoogde implantatieniveau 0,5 cm onder het kraakbeenniveau was. Het implantatieniveau werd gemeten op vier randen van ieder implantaat. Intra-articulaire contactdrukken werden gemeten voor en na implantatie met drukkrachten van 1000 tot 2000 N en het enkelgewricht in plantigrade positie, 10° dorsaalflexie en 14° plantairflexie. Een passende kromming van het implantaat was beschikbaar voor iedere talus. Het gemiddelde implantatieniveau was 0,45 ± 0,18 mm onder het kraakbeenniveau. De mediane contactdruk over het defectgebied bedroeg 3% (range 0,02% - 18%) van de totale contactdruk voor implantatie. Na implantatie was dit verminderd naar 0,1% (range 0,02% - 13%). Deze resultaten suggereerden dat het implantaat veilig klinisch toegepast kan worden, met geschikte krommingsmaten voor diverse talus geometrieën en zonder verhoogde contactdruk op het tegenoverliggende kraakbeen.

Hoofdstuk 10
Behandeling van secundaire osteochondrale defecten van de talus met een metalen implantaat: een prospectieve studie

Het doel van hoofdstuk 10 was het evalueren van de klinische effectiviteit van het metalen implantaat voor OD's van de mediale talusrol na falen van eerdere chirurgische behandeling. 20 opeenvolgende patiënten in de leeftijd van 20 tot 60 jaar (gemiddelde 38 jaar) werden prospectief bestudeerd gedurende 2 tot 5 jaar (gemiddelde 3 jaar). Er was een statistisch significante verbetering in pijn in elk van vier situaties (i.e. rust, lopen, traplopen en hardlopen; $p \leq 0{,}01$). De mediane AOFAS score verbeterde van 62 (range 28 – 75) preoperatief naar 87 (range 42 – 100) bij de laatste follow-up ($p < 0{,}01$). De FAOS verbeterde significant op alle subschalen. De gemiddelde

SF-36 fysieke component verbeterde van 36 ± 8,2 preoperatief naar 45 ± 7,8 bij de laatste follow-up (p <0,01). De SF-36 mentale component veranderde niet significant. Op röntgenfoto's waren er bij twee patiënten progressieve degeneratieve veranderingen van het tegenoverliggende tibiaplafond. Bij een patiënt was een aanvullende operatie nodig voor het OD. Deze studie liet zien dat het metalen implantaat een veelbelovende behandeling is voor OD's van de mediale talusrol na falen van eerdere chirurgie.

Hoofdstuk 11
Richting van de schuine mediale malleolus osteotomie voor de chirurgische benadering van de talus

Een mediale malleolus osteotomie is vaak geïndiceerd voor de operatieve benadering van posteromediale OD's en fracturen van de talus. Om een congruent gewrichtsoppervlak te verkrijgen na refixatie moet de osteotomie loodrecht uitkomen in de kruising tussen tibiaplafond en de mediale malleolus. Het doel van hoofdstuk 11 was het bepalen van deze richting ten opzichte van de longitudinale tibia-as voor peroperatief gebruik. Gebruik makend van anteroposterieure röntgenfoto's en coronale CT-scans van 46 enkels (45 patiënten) met een OD van de talus, maten twee onafhankelijke beoordelaars de kruisingshoek tussen tibiaplafond en faces articularis van de mediale malleolus. De bissectrice van deze kruisingshoek was de osteotomie loodrecht op het gewrichtsoppervlak van de tibia. Deze osteotomie werd gemeten ten opzichte van de longitudinale tibia-as op de röntgenfoto's. ICC's werden berekend om de betrouwbaarheid van de metingen te beoordelen. De osteotomie was gemiddeld 57,5° ± 3,2° ten opzichte van het tibiaplafond op röntgenfoto's en 56,5° ± 2,8° op CT-scans. Deze osteotomie correspondeerde met 30,4° ± 3,7° ten opzichte van de longitudinale tibia-as. De intra- (ICC 0,90 tot 0,93) en interobserver (ICC 0,65 tot 0,91) betrouwbaarheid van deze metingen waren goed tot uitstekend. De conclusie was dat een mediale malleolus osteotomie die onder een gemiddelde hoek van 30º ten opzichte van de tibia-as wordt gericht loodrecht uitkomt in het tibia-kraakbeen en waarschijnlijk resulteert in een congruent gewrichtsoppervlak na repositie.

Hoofdstuk 12
Klinische tip: richtingshaakje voor een precieze mediale malleolus osteotomie

Het gebruik van een tasthaakje werd beschreven om de posterieure en anterieure delen van de kruising tussen het tibiaplafond en de mediale malleolus te identificeren, om zodoende een precieze osteotomie te kunnen verrichten.

Deel IV – Alternatieve behandeling

Hoofdstuk 13
Osteochondrale defecten van de talus: een nieuw diermodel in de geit

Een experimenteel diermodel van het enkelgewricht was niet beschikbaar. Het doel van hoofdstuk 13 was het in vivo testen van een nieuw ontwikkeld diermodel voor OD's van de enkel. OD's werden gecreëerd in de talus van achterpoten van geiten met behulp van een posterolaterale chirurgische benadering. De defecten werden opgevuld met autologe spongiosa of met gedemineraliseerde botmatrix (DBM) of leeg gelaten ter controle. Na 12 weken werden de tali geanalyseerd met behulp van röntgenfoto's, macroscopie, µCT, histologie, histomorfometrie en fluorescentiemicroscopie. Het bleek mogelijk een gestandaardiseerd OD te creëren in iedere talus. Het geïmplanteerde materiaal bleef in situ. De analyses toonden dat het meeste botweefsel gegenereerd was in de defecten behandeld met

spongiosa en het minste in de controledefecten. Onze bevindingen lieten zien dat een standaard OD kan worden gecreëerd in de talus middels een relatief eenvoudige procedure in een groot dier dat kwalitatieve en kwantitatieve evaluatie mogelijk maakt. Er werd geconcludeerd dat het model gebruikt kan worden in toekomstige experimenten om alternatieve behandelmethoden te onderzoeken voordat ze in de klinische praktijk worden geïntroduceerd.

Hoofdstuk 14
Gedemineraliseerde botmatrix en plaatjesrijk plasma voor osteochondrale defecten van de talus: een experimentele geitenstudie

Het doel van hoofdstuk 14 was het evalueren van de effectiviteit van DBM met en zonder plaatjesrijk plasma (PRP) in de behandeling van OD's van de talus. Onze hypotheses waren dat behandeling met DBM zou leiden tot meer botvorming vergeleken met controledefecten en dat PRP de regeneratieve capaciteit van DBM verder zou verbeteren. Een standaard 6 mm OD werd gecreëerd in beide tali van 16 volwassen geiten. Volgens een randomisatieschema werd een OD van iedere geit behandeld met allogeen DBM gehydreerd met fysiologisch zout (n = 8) of gehydreerd met autoloog PRP (n = 8). Het contralaterale OD (n = 16) werd niet behandeld ter controle. Na 24 weken werden de dieren geobduceerd en de tali geëxcideerd. Verscheidene uitkomstparameters werden geanalyseerd met behulp van macroscopische evaluatie, µCT, histologie, histomorfometrie en fluorescentiemicroscopie. Geen van de analyses toonde een statistisch significant verschil tussen de groepen. Bijvoorbeeld, de gemiddelde botvolumefractie, gemeten met µCT, was 0,56 ± 0,17 in DBM gehydreerd met fysiologisch zout en 0,52 ± 0,18 in DBM gehydreerd met PRP, vergeleken met 0,53 ± 0,12 en 0,54 ± 0,14 in interne controles, respectievelijk (p >0,05). In tegenstelling tot onze hypotheses werd geen gunstig behandeleffect van DBM met of zonder PRP gevonden in OD's van de geitentalus.

Deel V – Uitkomstmaten

Hoofdstuk 15
Uitkomstmaten

De beoordeling van uitkomsten is essentieel bij de evaluatie van orthopedische procedures. In hoofdstuk 15 werden veelgebruikte klinische uitkomstmaten bediscussieerd. Verder werden scoringssystemen besproken die gebaseerd zijn op postoperatieve beeldvorming. De volgende conclusies werden getrokken: (1) de AOFAS score is een vaak gebruikte uitkomstmaat voor OD's van de talus, maar heeft enkele beperkingen, (2) de FAOS en de Foot and Ankle Ability Measure zijn functionele, patiëntgerapporteerde uitkomstmaten die nuttig zijn bij de klinische beoordeling van patiënten met een OD van de talus, (3) de 11-punts numerieke rating schaal is een geschikte, valide en praktische schaal voor de beoordeling van pijnintensiteit en (4) postoperatieve beeldvorming kan worden gebruikt voor objectieve beoordeling van herstelweefsel.

Hoofdstuk 16
Vertaling en validatie van de Duitse Foot en Ankle Outcome Score

De FAOS is een vragenlijst bestaande uit 42 items die worden onderverdeeld in vijf subschalen. De score is gevalideerd in diverse talen. Duitsland had geen gevalideerde uitkomstmaat voor algemene voet- en enkelpathologie. Het doel van dit hoofdstuk was het ontwikkelen van een Duitse versie van de FAOS en het onderzoeken van de psychometrische eigenschappen. Voor- en achterwaartse vertalingen werden gemaakt volgens officiële richtlijnen. De uiteindelijke

vertaling van de FAOS werd onderzocht in 150 patiënten met verscheidene aandoeningen van voet en enkel. Alle patiënten vulden de FAOS, SF-36, numerieke rating schalen voor pijn en invaliditeit en de Hannover vragenlijst in. De FAOS werd 1 week later opnieuw ingevuld. Test-retest betrouwbaarheid en interne consistentie van iedere subschaal waren uitstekend (ICC 0,88 tot 0,95; Cronbach's alfa 0,94 tot 0,98). De minimaal detecteerbare verschillen waren 17,1 tot 20,8 op individueel niveau en 2,0 tot 2,4 op groepsniveau. Er waren middelmatige tot sterke correlaties tussen FAOS subschalen en fysieke uitkomsten en lage tot middelmatige correlaties tussen FAOS subschalen en mentale uitkomsten. Bodem- en plafondeffecten waren niet aanwezig. Deze bevindingen lieten zien dat de Duitse versie van de FAOS een betrouwbaar en valide instrument is voor gebruik in voet- en enkelpatiënten.

Algemene discussie en samenvatting

Hoofdstuk 17
Algemene discussie

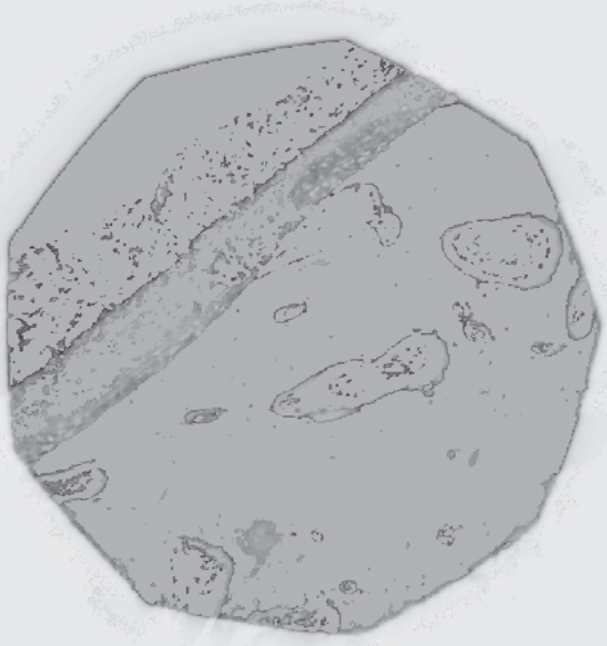
De behandeling van OD's van de talus vormt een uitdaging voor de orthopedisch chirurg. Dit proefschrift heeft op verschillende manieren bijgedragen aan de behandeling van patiënten met een OD in de talus. Een overzicht van de literatuur en een behandelalgoritme werden gepresenteerd. De lange termijn uitkomsten van artroscopische beenmergstimulatie bevestigden de duurzaamheid van de techniek en verschaften een referentiestandaard voor andere procedures om te evenaren. CT-scans toonden aan dat bijna de helft van de talusrol toegankelijk is in de anterieure werkruimte met de enkel in volledige plantairflexie. De studie naar versneld herstel met PEMF duurt nog enkele maanden voor de laatste follow-up. Een nieuwe metalen implantatietechniek leidde tot goede klinische uitkomsten in de meeste patiënten na een gemiddelde follow-up van 3 jaar. Een mediale malleolus osteotomie voor de chirurgische benadering van de talus komt loodrecht uit in het gewricht in de kruising tussen tibiaplafond en mediale malleolus wanneer deze gericht wordt onder een gemiddelde hoek van 30° ten opzicht van de longitudinale tibia-as. DBM en PRP werden onderzocht in een nieuw ontwikkeld geitenmodel. Ze bleken niet effectief in de behandeling van geiten OD's vergeleken met controledefecten. Ten slotte werden verscheidene uitkomstmaten besproken en werd een richtlijn gegeven voor het gebruik. De Duitse versie van de FAOS werd vertaald en gevalideerd.

Verschillende aanbevelingen kunnen worden gegeven voor de behandeling van OD's van de talus op basis van het proefschrift en de huidige literatuur. Artroscopische beenmergstimulatie blijft de primaire behandeling van chronische defecten tot 15 mm. Als de primaire behandeling faalt, blijven er diverse secundaire behandelingen over, waaronder mozaïekplastiek, (matrix-geïnduceerde) autologe chondrocyten implantatie, spongiosaplastiek en het metalen implantaat. De keuze hangt af van karakteristieken van patiënt en OD, evenals de voorkeur van de chirurg.

Er zijn nog vele mogelijkheden voor toekomstig onderzoek om het perspectief van patiënten met een OD van de talus verder te verbeteren. Toekomstig onderzoek zou zich moeten richten op het verbeteren van de beenmergstimulatie techniek, bijvoorbeeld door het identificeren van de meest effectieve diepte en afstand van penetratie van het subchondrale bot. Het ultieme doel van OD behandeling is het regenereren van de complete osteochondrale laesie met een constructie die resulteert in herstel van het subchondrale bot en een geïntegreerde laag hyaliene kraakbeen. Inferieure methoden zullen echter moeten worden gebruikt tot een dergelijke ideale behandeling beschikbaar is.

Grote diversiteit en variabiliteit tussen studies verschaffen de chirurg interessante keuzes waarin een belangrijke rol voor de patiënt en zijn of haar behoeften is weggelegd. Gerandomiseerde, gecontroleerde studies met voldoende power en uniforme methodologie en gevalideerde uitkomsmaten, evenals de optimalisering van huidige en de ontwikkeling van nieuwe behandelmethoden, kunnen de basis vormen voor het optimale behandelplan van toekomstige OD's van de talus.

Addendum



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Secretariaat, Marga Lammerts en Rosalie C.M. van de Sandt. Dank voor de administratieve ondersteuning.

Kweekvijvercollega's, dr. Laurens Kaas, drs. Peter A.J. de Leeuw, drs. Jakob van Oldenrijk, drs. Bas van Ooij, drs. Mikel L. Reilingh, dr. Maayke N. van Sterkenburg, drs. Sjoerd Stufkens en drs. Maartje Zengerink, een diverse groep mensen met een gemeenschappelijke liefde voor de orthopedie. Dank voor de gezelligheid op de werkvloer en zeker ook daarbuiten. De congressen, cursussen, borrels en feestjes houden we er de komende jaren in.

Paranimfen, drs. Jakob van Oldenrijk en drs. Wybren A. van der Wal, collega's en vrienden. Jakob, uit dezelfde kweekvijver, vooropleiding en vervolgopleiding. Op mijn eerste werkdag vroeg je je openlijk af waarom ik in hemelsnaam voor onderzoek had gekozen. Dat heb ik mijzelf ook nog wel eens afgevraagd, maar kijk wat er van geworden is. Wybren, fantastisch dat we sinds het eerste studiejaar vrienden zijn, prachtige reizen hebben gemaakt, feesten hebben bezocht, collega's orthopedisch chirurg worden en nu ook nog op onderzoeksgebied verbonden zijn.

Vrienden. Hoewel jullie niet direct hebben bijgedragen aan het proefschrift heb ik veel baat gehad van de broodnodige afleiding en jullie relativeringsvermogen. Fenny, over het hele traject ben jij een luisterend oor geweest en heb je me geadviseerd en gesteund waar nodig. Dank voor jullie begrip als ik er weer niet bij kon zijn.

Familie, Jan, Toos, Mathijs, Mariëlle, Rymond en Vasco, dierbaarsten. Ik ben zo gelukkig met ons gezin, teveel mooie herinneringen om op te noemen. Dank voor jullie eeuwige interesse en onvoorwaardelijke steun.

Dankwoord

Zonder de hulp van velen had dit proefschrift niet tot stand kunnen komen. Naast dank aan alle patiënten die mee hebben gewerkt gaat mijn dank in het bijzonder uit naar:

Promotor, prof. dr. C. Niek van Dijk, een pionier in de artroscopische chirurgie en gedreven begeleider met een scala aan onderzoeksideeën, die de promovendus vervolgens volledig vrij spel kan geven in de uitvoering. Ik ben vereerd met een wereldleider in de enkelchirurgie als promotor en verbondenheid aan de Amsterdamse school. Dank voor de geboden kansen in het promotie-onderzoek, in de organisatie van de befaamde enkelcursus en niet in de laatste plaats in de specialisatie tot orthopedisch chirurg.

Co-promotor, dr. ir. Leendert Blankevoort, een rasechte wetenschapper die vanuit zijn werkkamer (die inmiddels tweemaal zo groot is geworden) met immer kritisch commentaar het onderzoek naar een hoger niveau kan tillen. Waar een mapje met PEMF-aantekeningen dat ik op mijn bureau vond al niet toe kan leiden. Dank voor je precieze correcties van de manuscripten, waardoor de reviewers van tijdschriften vaak vrijwel geen werk meer hadden.

Co-promotor, dr. Gino M.M.J. Kerkhoffs, een bevlogen orthopedisch chirurg met liefde voor het vak, in de breedste zin van het woord, en voor het leven daarbuiten. Bij je terugkomst uit Zwitserland waren de meeste onderzoeken al in volle gang, maar door je betrokkenheid en enthousiasme heb je alsnog essentiële bijdragen geleverd aan een groot deel van het proefschrift. Bij jou heb ik mijn eerste osteochondraal defect behandeld. Je interesse in de mens achter de collega en achter de patiënt vormen een inspiratiebron.

Overige leden van de promotiecommissie, prof. dr. Rob J. de Haan, dr. Rover Krips, prof. dr. Mario Maas, prof. dr. Roelof-Jan Oostra, prof. dr. Daniël B.F. Saris en dr. ir. Gabriëlle J.M. Tuijthof, een veelzijdige commissie vooraanstaande wetenschappers. Dank voor het beoordelen van en interesse in het manuscript.

Statisticus, drs. Inger N. Sierevelt, een goudeerlijke vraagbaak bij wie de deur altijd open staat voor overleg. Dank voor je rake adviezen en statistische hulp bij vrijwel alle hoofdstukken, zelfs na je vertrek.

Werktuigbouwkundig ingenieur, dr. ir. Gabriëlle J.M. Tuijthof, een gepassioneerde uitvinder van orthopedische instrumenten met innovatieve ideeën. Dank voor de fijne samenwerking bij de CT en mediale malleolus osteotomie studies.

Opvolgers, drs. Mikel L. Reilingh en drs. Inge C.M. van Eekeren, gemotiveerde promovendi. Dank voor het feilloos oppakken van de onderzoeksthema's en de 100% follow-up van patiënten uit de prospectieve studies. Ik kijk uit naar jullie proefschriften.

Overige co-auteurs, drs. Christoph Becher, drs. Geert van Damme, prof. dr. Vincent Everts, dr. Daniël Haverkamp, drs. Paul Hoogervorst, drs. Pieter R.N. d'Hooghe, prof. dr. Jón Karlsson, dr. Clara M. Korstjens, drs. Laura S. Kox, drs. Peter A.J. de Leeuw, drs. Nick Marsidi, dr. Duncan E. Meuffels, drs. Jakob van Oldenrijk, drs. Murat Özdemir, dr. Leo J. van Ruijven, drs. Karin G. Silbernagel, dr. Maayke N. van Sterkenburg, drs. Hazibullah Waizy en drs. Maartje Zengerink, zeergewaardeerde collega's die het mogelijk hebben gemaakt een dergelijk veelzijdig proefschrift af te leveren. Veel dank voor eenieders onmisbare bijdrage.

Secretariaat, Marga Lammerts en Rosalie C.M. van de Sandt. Dank voor de administratieve ondersteuning.
Kweekvijvercollega's, dr. Laurens Kaas, drs. Peter A.J. de Leeuw, drs. Jakob van Oldenrijk, drs. Bas van Ooij, drs. Mikel L. Reilingh, dr. Maayke N. van Sterkenburg, drs. Sjoerd Stufkens en drs. Maartje Zengerink, een diverse groep mensen met een gemeenschappelijke liefde voor de orthopedie. Dank voor de gezelligheid op de werkvloer en zeker ook daarbuiten. De congressen, cursussen, borrels en feestjes houden we er de komende jaren in.

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Reilingh ML, van Bergen CJA, van Dijk CN: Diagnosis and treatment of osteochondral defects of the ankle. S Afr Orthop J 2009;8(2):44-50.

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Book chapters

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de Leeuw PAJ, van Sterkenburg MN, van Bergen CJA, van Dijk CN: Posterior ankle arthroscopy and endoscopy. In: Saxena A (ed): International advances in foot and ankle surgery, Springer-Verlag, London, 2012, Ch. 39, p. 419-30.

Podium presentations

van Bergen CJA, Reilingh ML, van Eekeren ICM, Gerards RM, Kerkhoffs GMMJ, Krips R, Meuffels DE, Sierevelt IN, de Haan RJ, Blankevoort L, van Dijk CN: Pulsed electromagnetic fields after arthroscopic treatment for osteochondral defects of the talus: double-blind randomized controlled multicenter trial. 2nd International Congress on Cartilage Repair of the Ankle (ICCRA), Prague, April 11 – 12, 2014 (invited).

Commandeur J, van Bergen CJA, Breederveld RS: Kitesurfing and windsurfing injuries at the North Sea over a 2-year period. 14th European Congress of Trauma and Emergency Surgery (ECTES), Lyon, May 4 – 7, 2013.

van Bergen CJA: Osteochondral defects of the talus: diagnostics and primary treatment. Danish Foot and Ankle Society (DFAS) Annual meeting. Copenhagen, May 1, 2013 (invited).

van Bergen CJA: Talus HemiCAP: the Amsterdam experience. DFAS Annual meeting. Copenhagen, May 1, 2013 (invited).

van Bergen CJA: Osteochondral defects of the talus: state of the art today. DFAS Annual meeting. Copenhagen, May 1, 2013 (invited).

van Eekeren ICM, van Bergen CJA, van Dijk CN: Second look arthroscopic findings after metal implantation for osteochondral defects of the talus. 2013 American Academy of Orthopaedic Surgeons (AAOS) Annual meeting, Chicago, March 19 – 23, 2013.

van Eekeren ICM, van Bergen CJA, Reilingh ML, Pereira H, van Dijk CN: Metallic resurfacing for the treatment of secondary defects of the talus. Preliminary results of a prospective clinical study. XXXII Congresso Nacional de Orthopedia a Traumatologia, Marina Vilamoura, October 17 – 19, 2012.
Winner Best free paper foot and ankle

van Dijk CN, van Eekeren ICM, van Bergen CJA: Hemicap. International Cartilage Repair Society (ICRS) Focus meeting foot and ankle, Zurich, August 30 – September 1, 2012 (invited).

van Dijk CN, van Eekeren ICM, van Bergen CJA, Reilingh ML: Metal implantation resurfacing for secondary osteochondral defects of the talus. 15th European Society of Sports traumatology, Knee surgery and Arthroscopy (ESSKA) Congress, Geneva, May 2 – 5, 2012 (invited).

Kerkhoffs GMMJ, van Eekeren ICM, Kok AC, van Bergen CJA: The role of PRP and other agents/techniques to improve and optimize the results of debridement and bone marrow stimulation. ESSKA – Ankle and Foot Associates (AFAS) Day 2012, Moscow, April 13, 2012 (invited).

van Dijk CN, van Eekeren ICM, van Bergen CJA, Reilingh ML: Metal implantation resurfacing for secondary osteochondral defects of the talus. ESSKA – AFAS Day 2012, Moscow, April 13, 2012 (invited).

van Bergen CJA, van Dijk CN: Metal implantation for secondary osteochondral defects of the talus. ICCRA, Dublin, March 9 – 10, 2012 (invited).

van Bergen CJA, Reilingh ML, van Dijk CN: Metal implantation for secondary osteochondral defects of the talus: a prospective study. 2012 AAOS Annual meeting, San Francisco, February 7 – 11, 2012.

van Bergen CJA, Kox LS, Maas M, Sierevelt IN, Kerkhoffs GMMJ, van Dijk CN. Long-term follow-up after arthroscopic treatment of osteochondral defects of the talus. 2012 AAOS Annual meeting, San Francisco, February 7 – 11, 2012.

Reilingh ML, van Bergen CJA, van Dijk CN: Novel metallic implantation technique for osteochondral defects of the medial talar dome. British Orthopaedic Foot & Ankle Society (BOFAS) Annual meeting, Old Windsor, November 2 – 4, 2011.
Abstract: J Bone Joint Surg Br 2012;94(Suppl XLIII):41.

Reilingh ML, van Bergen CJA, Gerards RM, van Dijk CN: Postoperatieve losse fragmenten na artroscopische nettoyage en microfracturing van osteochondrale defecten van de talus. Nederlandse Orthopaedische Vereniging (NOV) Najaarsvergadering, Noordwijkerhout, October 6 – 7, 2011.
Abstract: Ned Tijdschr Orthop 2011;18(3):137-8.

van Bergen CJA, Özdemir M, Kerkhoffs GMMJ, Korstjens CM, van Ruijven LJ, Everts V, van Dijk CN, Blankevoort L: Demineralized bone matrix and platelet-rich plasma for osteochondral defects of the talus: an experimental goat study. 12th European Federation of National Associations of Orthopaedics and Traumatology (EFORT) Congress, Copenhagen, June 1 – 4, 2011.
Abstract: J Bone Joint Surg Br 2012;94(Suppl XXXVII):149.

van Bergen CJA, Reilingh ML, van Dijk CN: Metal implantation resurfacing for secondary osteochondral defects of the talus: first results of a prospective clinical study. 12th EFORT Congress, Copenhagen, June 1 – 4, 2011.
Abstract: J Bone Joint Surg Br 2012;94(Suppl XXXVII):234.

van Bergen CJA, Tuijthof GJM, Blankevoort L, Maas M, Kerkhoffs GMMJ, van Dijk CN: Preoperative planning of arthroscopic access to the talus with computed tomography of the ankle in full plantar flexion. 12th EFORT Congress, Copenhagen, June 1 – 4, 2011.
Abstract: J Bone Joint Surg Br 2012;94(Suppl XXXVII):233.
Abstract: Orthop Today 2011;Sept:9.
Nomination EFORT free paper award

van Bergen CJA, Özdemir M, Kerkhoffs GMMJ, Korstjens CM, van Ruijven LJ, Everts V, van Dijk CN, Blankevoort L: Demineralized bone matrix and platelet-rich plasma for osteochondral defects of the talus: an experimental goat study. 8th biennial International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine (ISAKOS) Congress, Rio de Janeiro, May 15 – 19, 2011.
Nomination Scientific research award

van Bergen CJA, Kerkhoffs GMMJ, Özdemir M, Korstjens CM, van Ruijven LJ, Everts V, van Dijk CN, Blankevoort L: Gedemineraliseerde botmatrix en plaatjesrijk plasma voor osteochondrale defecten van de talus. NOV Jaarvergadering, Groningen, January 27 – 28, 2011.
Abstract: Ned Tijdschr Orthop 2011;18(1):44.

Knupp M, Stufkens SA, Bolliger L, van Bergen CJA, Hintermann B: Supramalleolar osteotomies: biomechanical background and clinical results. 26th American Orthopaedic Foot & Ankle Society (AOFAS) Annual summer meeting, Washington, July 7 – 10, 2010.

van Bergen CJA, Kox LS, Maas M, Sierevelt IN, Kerkhoffs GMMJ, van Dijk CN: Long-term outcome after arthroscopic treatment of osteochondral talar defects. ESSKA – American Orthopaedic Society for Sports Medicine (AOSSM) Travelling fellowship academic session, Amsterdam, May 17, 2010 (invited).

Stufkens SA, Knupp M, van Bergen CJA, Blankevoort L, van Dijk CN, Hintermann B: Ankle joint changes in distal tibia varus and valgus. 2010 AAOS Annual meeting, New Orleans, March 9 – 13, 2010.

van Bergen CJA, Kerkhoffs GMMJ, Marsidi N, Korstjens CM, Everts V, van Ruijven LJ, van Dijk CN, Blankevoort L: Effective evaluation of alternative treatment methods for osteochondral lesions of the talus: a new animal model. Nederlandse Vereniging voor Calcium- en Botstofwisseling (NVCB) Jaarvergadering, Zeist, November 12 – 13, 2009.

van Bergen CJA, Kerkhoffs GMMJ, Marsidi N, Korstjens CM, Everts V, van Ruijven LJ, van Dijk CN, Blankevoort L: Osteochondrale laesies van de talus: een nieuw geitenmodel. 22e Symposium Experimenteel Onderzoek Heelkundige Specialismen (SEOHS), Nijmegen, November 6, 2009.
Winner Best presentation

van Bergen CJA, Kox LS, Maas M, Sierevelt IN, van Dijk CN: 8 – 18 years' results of ankle arthroscopy for osteochondral lesions of the talus. 2nd Mini-Invasive Surgery of the Foot and Ankle (MISFA) International congress, Murcia, April 23 – 25, 2009.

van Bergen CJA, Zengerink M, Blankevoort L, van Dijk CN: Cadaveric study of a novel metallic implant for osteochondral defects of the medial talar dome. 2nd MISFA International congress, Murcia, April 23 – 25, 2009.

van Bergen CJA, Kox LS, Maas M, van Dijk CN: Artroscopische behandeling van osteochondraal defecten van de talus: lange termijn follow-up. NOV Jaarvergadering, Rosmalen, January 15 – 16, 2009.

van Bergen CJA, Sluijs DE, Thijssen LEH, Pijnenburg ACM: Suture anchor fixation of the ruptured distal biceps tendon through a single-incision approach. 54th Nordic Orthopaedic Federation (NOF) Congress, Amsterdam, June 11 – 13, 2008.

van Bergen CJA, Zengerink M, Blankevoort L, van Dijk CN: Partial resurfacing for osteochondral defects of the medial talar dome: a biomechanical cadaver study. 54th NOF Congress, Amsterdam, June 11 – 13, 2008.

van Bergen CJA, Zengerink M, Blankevoort L, van Dijk CN: Partial resurfacing for osteochondral defects of the medial talar dome. ESSKA – AOSSM Travelling fellowship academic session, Amsterdam, May 13, 2008 (invited).

van Bergen CJA, Sluijs DE, Thijssen LEH, Pijnenburg ACM: Anatomical reconstructions of distal biceps tendon ruptures. 18e Nederlandse Vereniging voor Artroscopie (NVA) Jaarvergadering, Ermelo, March 21, 2008.

Poster presentations

van Bergen CJA, Tuijthof GJM, Sierevelt IN, van Dijk CN: Optimale richting van de mediale malleolus osteotomie ter benadering van de talus. Traumadagen, Amsterdam, November 11 – 12, 2010.

van Bergen CJA, Kox LS, Maas M, Sierevelt IN, van Dijk CN: Ankle arthroscopy for osteochondral defects of the talus: outcome after 8 to 20 years. 14th ESSKA Congress, Oslo, June 9 – 12, 2010.
Abstract: Knee Surg Sports Traumatol Arthrosc 2010;18(Suppl 1):S313.

van Bergen CJA, Reilingh ML, van Dijk CN: Novel metal implantation technique for secondary osteochondral defects of the talus: preliminary results. 14th ESSKA Congress, Oslo, June 9 – 12, 2010.
Abstract: Knee Surg Sports Traumatol Arthrosc 2010;18(Suppl 1):S314-15.

van Bergen CJA, Kerkhoffs GMMJ, Marsidi N, Korstjens CM, Everts V, van Ruijven LJ, van Dijk CN, Blankevoort L: Osteochondral defects of the talus: a novel animal model. 14th ESSKA Congress, Oslo, June 9 – 12, 2010.
Abstract: Knee Surg Sports Traumatol Arthrosc 2010;18(Suppl 1):S310-11.

van Bergen CJA, Tuijthof GJM, van Dijk CN: Oblique medial malleolar osteotomy for exposure of the talus. 14th ESSKA Congress, Oslo, June 9 – 12, 2010.
Abstract: Knee Surg Sports Traumatol Arthrosc 2010;18(Suppl 1):S313-14.

van Bergen CJA, Sluijs DE, Thijssen LEH, Pijnenburg ACM: Anatomische reconstructie van distale bicepspeesrupturen. Wetenschappelijk sportmedisch congres Vereniging voor Sportgeneeskunde (VSG), Noordwijkerhout, November 29 – 30, 2007.

Curriculum vitae

Christiaan van Bergen was born in Wijk bij Duurstede, the Netherlands, on November 19, 1980. After graduating from high school (VWO, Revius Lyceum, Doorn) in 1999, he studied medical school at Utrecht University. After the first year of study, he went to Australia and Southeast Asia for a 1-year sabbatical. During medical study, he visited South Africa and Uganda for clinical internships. In the final year of study, a research internship at the department of orthopaedic surgery of the University Medical Center Utrecht (prof. dr. R.M. Castelein) and a clinical internship at the Diakonessenhuis Utrecht (dr. A.C.M. Pijnenburg) made him enthusiastic to continue in this working field. After obtaining the medical doctor's degree in 2006, he worked as a PhD student at the department of orthopaedic surgery of the Academic Medical Center Amsterdam (prof. dr. C.N. van Dijk), which finally resulted in this thesis. During the 3-year period, he organised the 8th and 9th Amsterdam Foot & Ankle Course and presented his research at national and international congresses. In 2010, he started his training for orthopaedic surgery at the department of general surgery of the Rode Kruis Ziekenhuis Beverwijk (prof. dr. R.S. Breederveld and dr. H.A. Cense). He continued his residency at the departments of orthopaedic surgery of the Academic Medical Center Amsterdam (prof. dr. C.N. van Dijk) and the Tergooi Ziekenhuizen Hilversum (dr. A.M.J.S. Vervest). He will continue at the Amphia Ziekenhuis Breda (dr. D. Eygendaal) and will finish his training at the Academic Medical Center Amsterdam at the end of 2015.