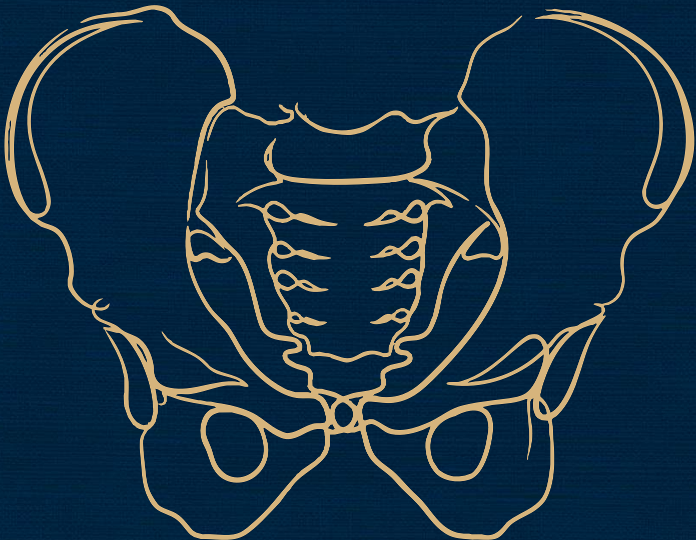
Clinical Challenges and Innovations in the Treatment of Pelvic Fractures



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Voor Florentine

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General introduction and outline of this thesis

Introduction
Pelvic fractures in general
Pelvic fractures present a wide spectrum of injury patterns. Numerous factors, including the mechanism of trauma, the amount of kinetic energy involved, bone quality, the patient's conditions, physiological age and pre-existing comorbidities significantly influence fracture morphology, clinical decision-making, and patient outcomes. In addition, the complex pelvic anatomy, which includes both bony structures and surrounding vital organs, makes these injuries among the most technically demanding and complex challenges in orthopedic trauma surgery today [1, 2]. Understanding the anatomical foundation of the pelvis is essential to fully grasp the clinical challenges associated with pelvic injuries.

The word *pelvis* originates from the Latin *pēluis*, meaning "basin" or "cavity" [3]. Anatomically, the pelvis is a ring-shaped structure composed of three bones: the sacrum and two hemipelves, also known as innominate bones [1, 4]. Each innominate bone is formed by the fusion of three separate bones: the ilium, the ischium, and the pubis. These three bones are fused during early development. The junction of these three bones forms the acetabulum on each lateral side of the pelvis, serving as a socket for the hip joint. The sacrum, formed by fusion of five embryonic sacral vertebrae, functions as the central hub connecting the spine to the pelvis. (**Figure 1**)

In addition to the bony architecture, the pelvis relies on a strong network of ligaments that provide essential stability. Posteriorly, the sacrum is connected to the innominate bones by strong sacroiliac ligaments, forming a critical biomechanical junction also known as the spinopelvic junction. This junction primarily facilitates load transmission from the spine to the lower extremities through the acetabulum and sacroiliac (SI) joints. Anteriorly, the two innominate bones are connected by the pubic symphysis, which completes the pelvic ring. Several other pelvic ligaments, such as the iliolumbar, sacrospinous, and sacrotuberous ligaments, further reinforce and support the pelvic floor, including the soft tissue structures contained within the pelvis (1,4; **Figure 1**) Disruption of these osteoligamentous structures severely compromises pelvic structural stability, often resulting in significant functional impairment. Even when treated appropriately, pelvic injuries are often associated with prolonged pain and loss of mobility.

The overall incidence of pelvic ring fractures in the general population is reported to be 0.82 per 100,000 people, comprising 2-3% of all fractures [1, 5]. Epidemiological studies have shown that pelvic ring fractures occur across all ages. However, the highest incidence is observed in younger patients, between 18 and 44 years of age [6]. Pelvic ring fractures in this patient group often result from high-energy trauma, such as traffic accidents or falls from height. These patients frequently present with multiple associated injuries, including thoracic trauma, long bone fractures, and head injuries.

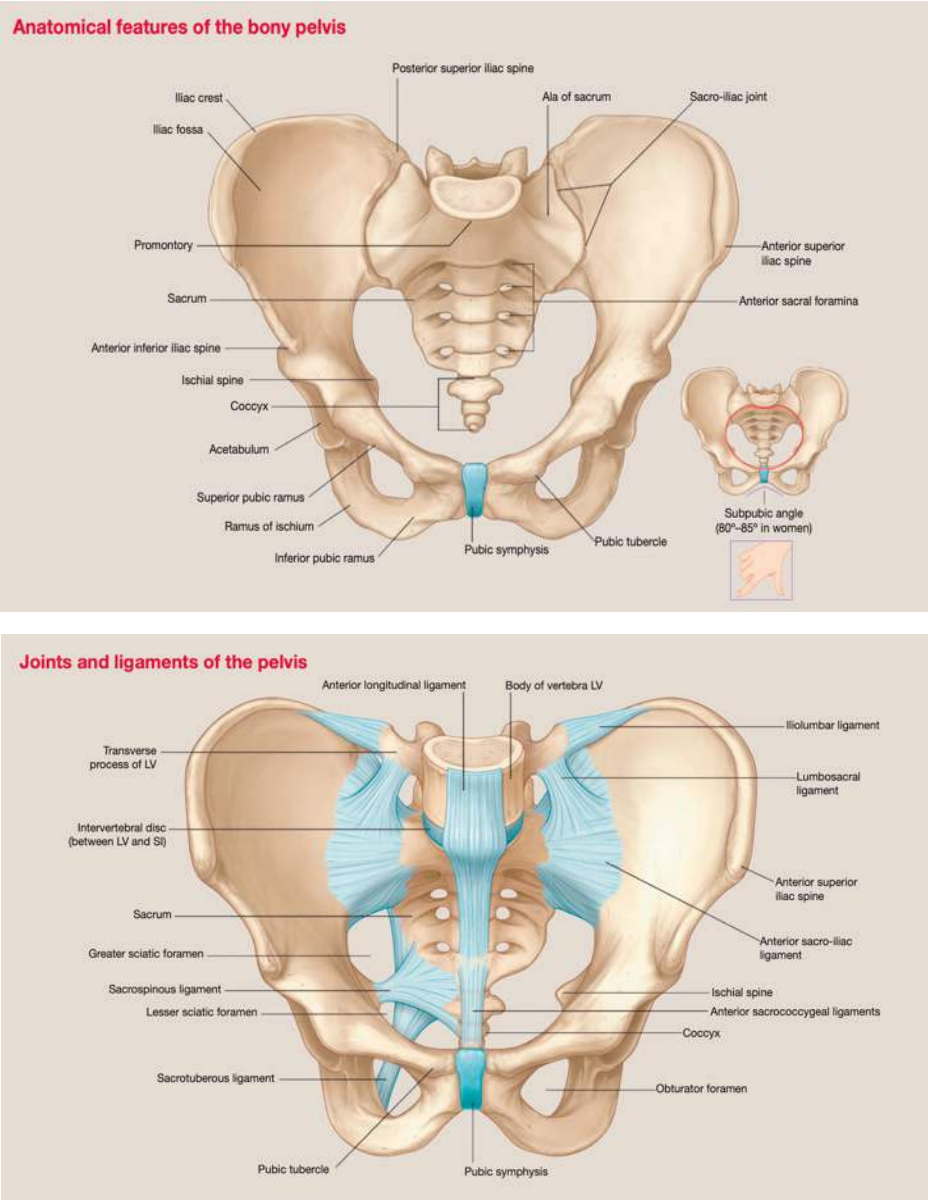

Figure 1. Anatomical features of the bony and ligamentous structures of the pelvis

In these high-energy trauma cases, substantial kinetic forces cause disruption of both the pelvic bone and ligamentous structures. The close proximity of major arterial and venous vessels makes these injuries particularly dangerous, as damage to these structures can result in life-threating hemorrhages occurring in 15-30% of the patients.

These injuries cause significant morbidity and mortality with mortality rates reported between 7 and 20% [5, 7, 8]. Given the severity of these injuries, initial management in high-energy trauma pelvic fracture patients focuses on life-saving, damage control procedures guided by the Advanced Trauma Life Support (ATLS) principles, including mass transfusion, temporary pelvic stabilization and/or pelvic packing [2, 8, 9]. Once stabilized, treatments shift toward restoring pelvic ring anatomy to maximize mobility and functional recovery, which is especially important in younger patients [1, 2, 8].

In contrast, pelvic ring fractures in elderly patients, particularly females aged 65 – 85 years, typically result from low-energy trauma and are seldom associated with immediate life-threatening injuries [10, 11]. These patients present a unique set of challenges including multiple comorbidities, decreased bone strength, and different treatment goals [10, 12].

Challenges in pelvic ring fractures through the ages.

The treatment of pelvic ring fractures has presented challenges across all ages. For centuries, pelvic ring fractures were considered fatal, as patients often succumbed to hemorrhage or associated injuries before reaching medical care. For patients who survived, non-operative management was the primary approach due to limited understanding of pelvic anatomy, fracture patterns, and mechanical stability [13]. Prior to radiographic diagnostics, pelvic fractures were diagnosed solely through physical examination. French surgeon Joseph-François Malgaigne (1806–1865) observed that careful palpation and manipulation to detect crepitus at the fracture site could diagnose a pelvic fracture with a high degree of certainty [13, 14]. He also noted that estimating the height of the iliac crest indicated vertical displacement of pelvic fracture, which was almost always associated with complete loss of function in the affected lower limb. Treatment focused on restoring limb length through closed reduction involving rectal and vaginal palpation combined with traction and pelvic sling maintained for a minimum of 45 to 50 days.

Following Malgaigne's pioneering, work, British surgeon Charles Hewitt Moore (1821–1870), is considered one of the founding fathers of modern pelvic fracture treatment [15]. Though Moore's clinical work is less well known to the public, his sole published article in 1851 offers a remarkably detailed analysis of the multiple deforming forces involved in pelvic fractures accompanied by detailed illustrations. At the time, these descriptions and illustrations were revolutionary, and it is believed that they later served as the foundation for early classification systems [16; **Figure 3**]

Despite these early insights, major medical advancements, such as the invention of general anesthesia by Willem Thomas Green in 1849 and the discovery of X-rays by Wilhelm Conrad Röntgen in 1895, only began to revolutionize fracture treatment. However, a systematic classification of pelvic fractures was developed until the late 20th century [13, 16].

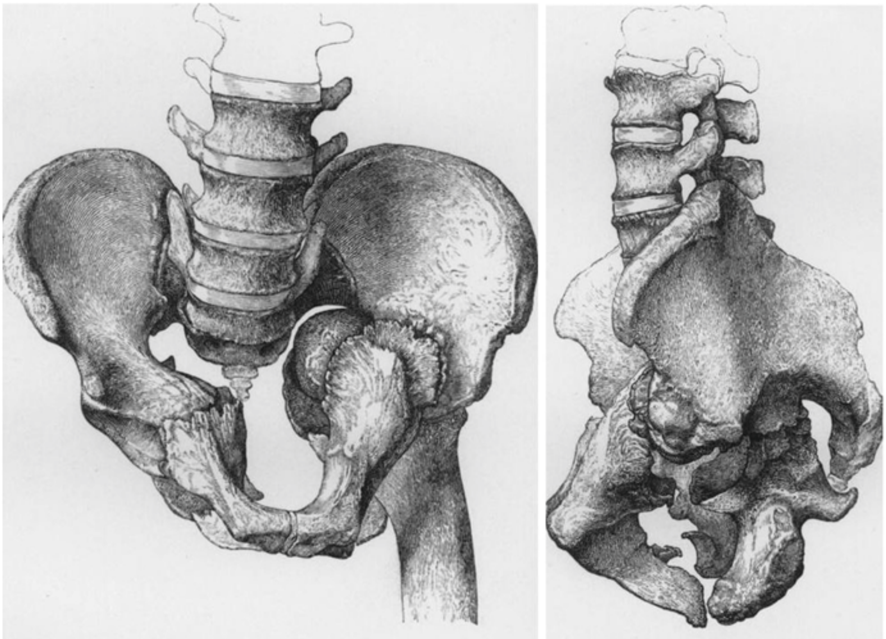

Figure 3. Orginal graphic artwork from Charles Hewitt Moore 1851

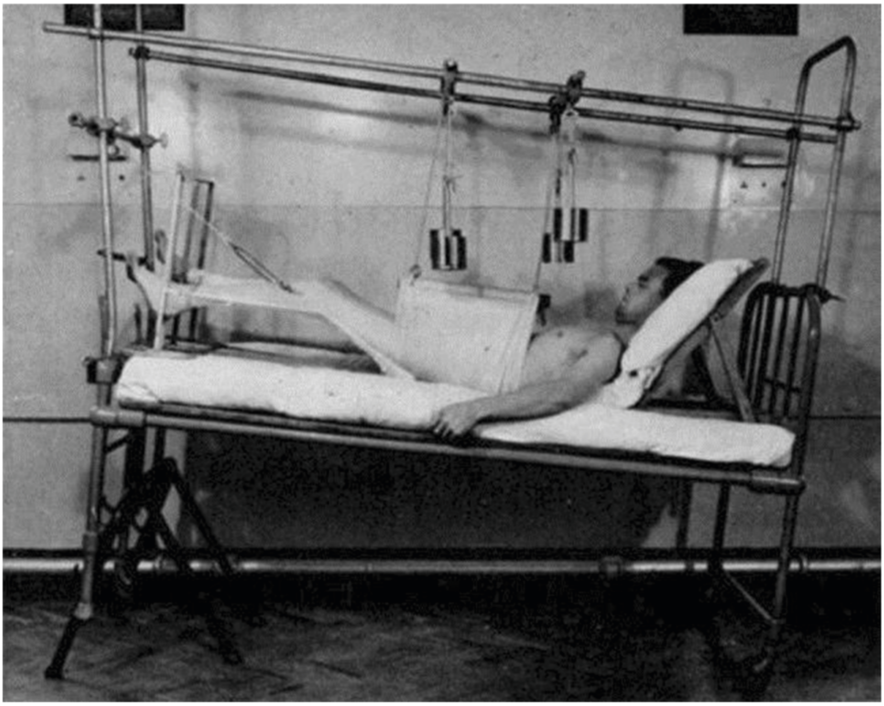

Figure 4. Non-operative treatment of pelvic fracture using skeletal traction in the early 1900's

In the late 1900s, Pennal and Sutherland introduced the first comprehensive classification system for pelvic and acetabular fractures, providing a structured understanding of different fracture patterns. Later, Pennal and Tile expanded this classification by incorporating mechanical stability, marking a pivotal shift toward a better understanding of these injuries and laying the groundwork for surgical fixation as the primary treatment [16]. At the time, this was groundbreaking, as nearly all pelvic fractures were still managed non-operatively based on the principles by Sir Frank Holdsworth (1904–1969). This treatment included prolonged bed rest and skeletal traction, sometimes lasting up to 12 weeks [18; **Figure 4**].

The early classification systems for pelvic fractures laid the foundation for modern frameworks such as the AO/OTA classification (based on Tile's system) and the Young and Burgess classification (based on Pennal and Sutherland) [17, 18]. During the mid-20th century, a surge in motor vehicle accidents brought pelvic ring fractures into focus as a major cause of morbidity and mortality. This increase accelerated the development of new treatment paradigms, ultimately shifting the primary treatment concepts for pelvic and acetabular fractures toward surgical fixation.

Although surgical techniques have advanced significantly advancements in over recent decades, the management of pelvic ring fractures remains complex and challenging. Consequently, clinicians continue to face challenges in managing these fractures and are actively seeking better ways to understand these injuries and optimize treatment outcomes.

Fragility Fractures of the Pelvis in an Aging Population

In the 21st century, the treatment landscape of pelvic ring fractures has shifted significantly due to a rising incidence of low-energy fractures, especially in the elderly. The Netherlands provides a good example for this demographic shift. As of January 1, 2024, 3,677,228 people (20.5% of the total population) were aged 65 or older, compared to only 12.8% in 1990 [19]. This rapid increase in the elderly population, often referred to as "grey pressure," is expected to continue, leading to greater demands on healthcare services, including chronic disease management and emergency care [19].

With this demographic shift, there has been a notable increase in fragility fractures, with hip fractures being one of the most prominent examples. In the Netherlands, hip fractures are among the most common injuries leading to hospital admissions, with over 20,000 cases annually. A large international study indicates that the health burden of hip fractures has grown significantly in recent years, with the Netherlands experiencing the highest increases. Furthermore, projections suggest that the global health burden of hip fractures will double by 2050, leading to greater dependency, morbidity, and mortality, placing an increasing strain on patients, their families, and healthcare systems [20, 21].

Although pelvic and acetabular fractures in the elderly do not yet match the incidence rates of proximal hip fractures, their occurrence has been rising at a significantly faster rate. Over the past decade in the Netherlands, the incidence of pelvic fractures among the elderly increased from 29.77 per 100,000 person-years in 2012 to 42.94 per 100,000 in 2022, a 44% increase [22]. The rise in acetabular fractures has been even more pronounced, with a 97% increase over the same period, from 4.03 to 8.23 per 100,000 person-years. In comparison, hip fractures remain more common but have grown at a slower rate, increasing by only 15% (from 116 to 133 per 100,000 person-years). Given the projected global rise in the health burden of hip fractures and extrapolating from these trends, fragility fractures of the pelvis are expected to become a major healthcare challenge, comparable to hip fractures.

As these fractures become more prevalent, it is critical to understand their underlying mechanism and diagnostic complexity. The principal underlying cause of low energy pelvic ring fractures in elderly is reduced bone strength due to osteoporosis, particularly affecting the sacral ala [23, 24]. Because of the loss of bone strength, Fragility Fractures of the Pelvis (FFPs) occur following minor trauma that would not result in a pelvic ring fracture in younger, healthy individuals [25-27]. Due to the non-specific pain presentation and the low bone density, diagnosing these fractures can be challenging. FFPs are easily missed on X-rays, and additional imaging techniques, such as CT scans or MRIs, are often required [28-30].

Furthermore, because of differences in bone density, fracture patterns observed in elderly patients can differ significantly from those seen in young patients. Current fracture classification systems, which are primarily based on high-energy trauma pelvic ring fractures, are deemed to be inadequate for categorizing these unique patterns in elderly patients [31]. Rommens et al. introduced a new classification system, which serves as a foundation for diagnosing and treating these complex fracture [32; **Figure 4**]. The Rommens classification categorizes FFPs in elderly patients based on fracture location and degree of instability, primarily assessed using CT-imaging. It distinguishes four fracture types, ranging from isolated anterior injuries (FFP I) to combined anterior and bilaterally unstable posterior lesions (FFP IV). The Rommens classification provides a structed framework for understanding and describing fracture patterns, but evidence supporting its prognostic validity remains limited.

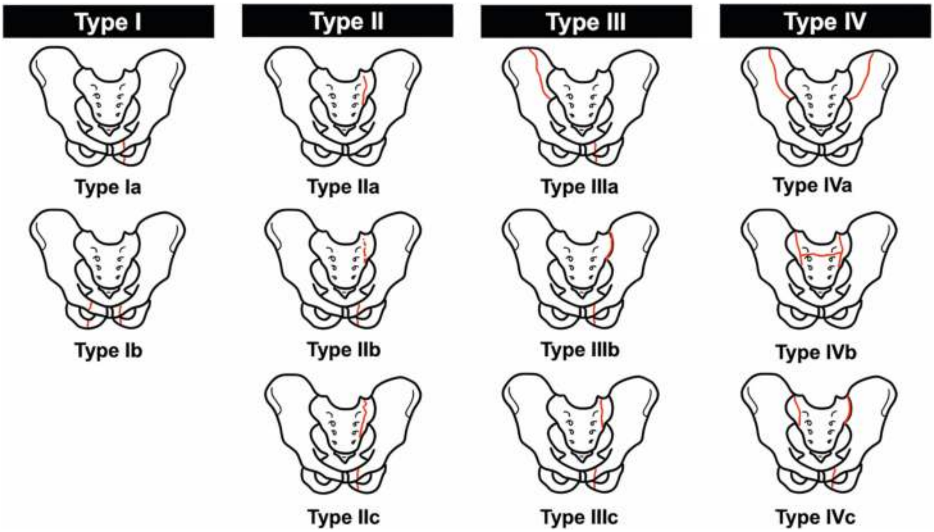

Figure 4. Rommens classification of fragility fractures of the pelvis
FFP Ia: unilateral anterior disruption; FFP Ib: bilateral anterior disruption; FFP IIa: isolated nondisplaced posterior injury; FFP IIb: sacral crush with anterior disruption; FFP IIc: nondisplaced sacral, sacroiliac, or iliac fracture with anterior disruption; FFP IIIa: displaced unilateral iliac fracture with anterior disruption; FFP IIIb: displaced unilateral sacroiliac disruption with anterior disruption; FFP IIIc: displaced unilateral sacral fracture with anterior disruption; FFP IVa: bilateral iliac fractures or bilateral sacroiliac disruptions with anterior disruption; FFP IVb: spinopelvic dissociation with anterior disruption; FFP IVc: combined posterior instabilities with anterior disruption.

Minimally invasive surgery in pelvic fractures

Minimally invasive surgery has evolved over the past decades as alternatives to, or modification of traditional surgical approaches, both in general and orthopedic surgery. The core principle is to achieve the same surgical results through smaller incisions, resulting in reduced soft tissue dissection, lower post-operative pain, and infection rates and shorter hospital stays, while still maintaining comparable functional outcomes. [36].

Historically, pelvic and acetabular surgeries have relied on extensive surgical exposure to ensure optimal visualization and achieve anatomical reduction, particularly in high-energy pelvic injuries with significant fracture displacement. However, the development of minimally invasive techniques, such as percutaneous antegrade/ retrograde screw fixation of the pubic rami, LC2 screw fixation of the anterior column of the acetabulum, percutaneous sacroiliac (SI) and transiliac-transsacral screw (TITS) fixation has enabled, a shift toward less invasive procedures [8, 37-40]. These techniques can either serve as standalone treatment or be used in combination with traditional open procedures. Elderly patients with low-energy pelvic ring fractures particularly benefit from minimally invasive surgery due to lower risk of surgical site infections and reduced post-operative pain thereby allowing early mobilization. [34, 35, 41].

Despite the benefits of minimally invasive surgery, a major limitation is the reduced tactile and visual feedback available to the surgeon. Pelvic anatomy is inherently complex, and navigating the sacral regions is particularly challenging. The narrow osseous corridors for percutaneous SI or TITS screw fixation are in close proximity to the sacral neural plexus [42]. Moreover, the presence of sacral dysmorphism can further complicate accurate screw positioning [42-44]. Even in the hands of experienced surgeons, screw misplacement using fluoroscopic guidance has been reported in up to 20% of cases [38, 45]. Screw misplacement, especially when perforating the neuroforamina, can potentially lead to sacral root injuries resulting in pain, loss of sensation, motor deficits of the lower limbs, and bladder or genital function [39, 46]. Advancements in intraoperative imaging, navigated screw placement systems, and development of specialized osteosynthesis implants are essential to mitigate these risks [47-50]. Further innovation in this area is paramount for development of safer minimally invasive surgical techniques with the goal of reducing postoperative complications and improving patient outcomes. Minimal invasive techniques will become increasingly essential, given the rising incidence of FFPs.

Outline of this thesis

While advancements in diagnostics and treatment techniques have improved patient outcomes, pelvic fractures remain a formidable clinical challenge. The treatment of pelvic and acetabular fractures is complicated by the risk of hemorrhage, infection, and mechanical instability, and the emergence of new patient populations, such as geriatric patients, adds further complexity.

This thesis evaluates some of the currently most significant clinical challenges of the treatment of pelvic fractures in both the traditional high-energy younger patient and the newly emerging elderly low-energy pelvic fracture patient cohort. It focuses specifically on:

- *Complications in treatment of pelvic fractures,* **PART I**
- *Treatment strategies for pelvic ring fractures in elderly patients,* **PART II**
- *Minimal invasive screw fixation in pelvic ring fractures,* **PART III**

PART I: Complications in treatment of pelvic ring fractures

The first part of this thesis focuses on complications in treatment of pelvic fractures in general. Over the past 40 years, extensive research has been conducted worldwide on acetabular and pelvic ring fracture surgery. The current body of literature primarily focuses on pelvic fractures in young individuals resulting from high-energy trauma and is heterogeneous in many aspects, including surgical techniques, outcome measurements, and complications. However, a clear and comprehensive overview of post-operative complications and their potential risk factors is lacking. In **CHAPTER 2** we examine surgical complications and risk factors in a cohort of Dutch patients from all ages with a pelvic ring and/or acetabular fracture. We identify independent risk factors for the development of surgical complications and provide advice on how to prevent them. **CHAPTER 3** provides a systematic review of the literature on post-operative complications associated with specific surgical approaches for treatment of pelvic ring and acetabular fractures. We analyzed the currently available literature to understand risk factors and enhance pre-operative decision making in management of pelvic fractures.

PART II: Treatment strategies for pelvic ring fractures in elderly patients

The second part of this thesis focuses on elderly patients with pelvic ring fractures. They present novel challenges in the field of traumatic pelvic ring injuries for several reasons including multi-comorbidities, different biomechanical behavior of fractures, use of anti-coagulants and different treatment goals with different indication for surgical fixation. In **CHAPTER 4** we review the current literature on the indications, timing and the role of fracture classification on surgical fixation of pelvic ring fractures in elderly. Furthermore, we try to identify the preferred type of fixation in this frail population.

CHAPTER 5 displays the results of a prospective multicenter cohort study including 102 elderly patients (>70 years old). This study researched the clinical implications of additional posterior fractures and evaluated the role of routine CT-scan evaluation in combined anterior-posterior pelvic ring fractures in elderly patients.

PART III: Minimal invasive screw fixation in pelvic ring fractures

The third part of this thesis focusses on novel minimally invasive screw fixation of pelvic ring fractures. Due to the improvement in diagnostic and peri-operative imaging and navigation techniques, the use of minimally invasive surgery for pelvic ring fractures has increased substantially. These techniques enable keyhole surgery, which has been shown to be safer regarding post-operative complications. Therefore, they can be a suitable option for operating on both vital and particularly frail patients, such as those with geriatric pelvic ring fractures. **CHAPTER 6** presents the results of a study investigating the safety and efficacy of 3D image-guided navigation in screw fixation for pelvic ring fractures compared to conventional 2D navigation. With a consecutive case series of 90 patients, the research evaluates screw misplacement rates, neurovascular complications, and infections associated with 3D navigation. **CHAPTER 7** investigates the indications for hardware removal of transiliac-transsacral (TITS) and sacroiliac (SI) percutaneous screw fixation for traumatic pelvic ring fractures. The primary objectives include determining the percentage of patients undergoing hardware removal and assessing the reasons for removal, such as pain, infection, screw-related issues, and nerve injuries. Furthermore, it evaluates the changes in pain, mobility, and general health before and after hardware removal and assesses which patients benefit most from hardware removal.

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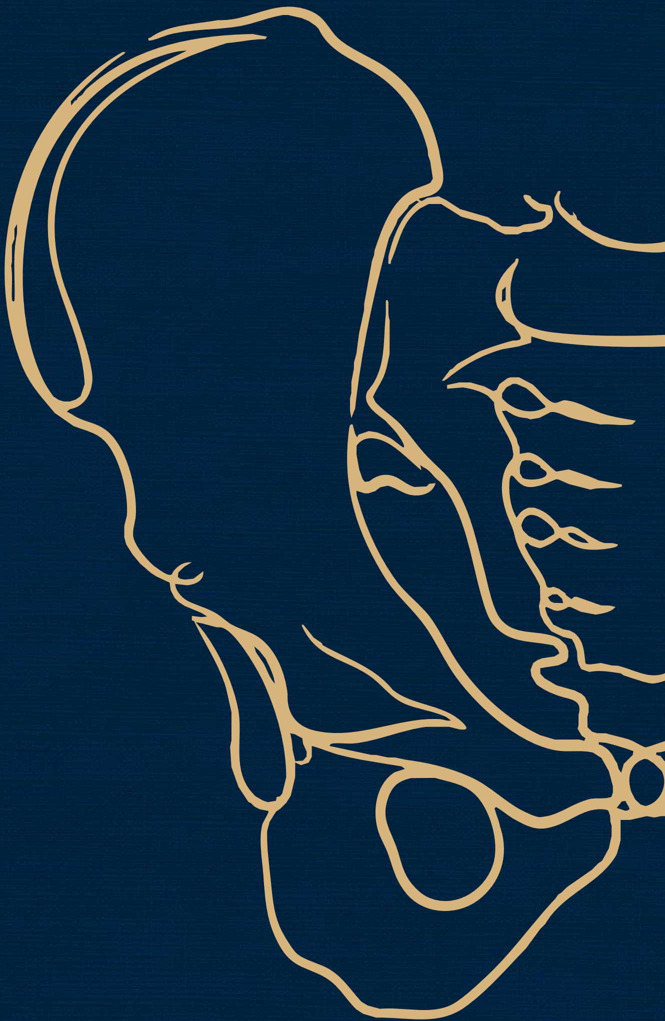

Part I

Complications in treatment of pelvic fractures

2

Rates and risk factors of complications associated with operative treatment of pelvic fractures

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C. Q. B. Mostert
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S. A. G. Meylaerts
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C. Q. B. Mostert and R. A. Timmer have contributed equally to this work.

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Abstract

Purpose

Post-operative complications following fixation of pelvic fractures can lead to increased morbidity and mortality. Available literature regarding complications is heterogeneous, and knowledge of risk factors is limited. This study aims to identify the most common post-operative complications and their possible risk factors following pelvic fracture surgery.

Methods

A retrospective cohort study was performed in two level-1 trauma centers in the Netherlands between January 2015 and January 2021. All adult patients (≥ 18 years) with an operatively treated pelvic fracture (pelvic ring and/or acetabular fractures) were included. Post-operative complications included surgical site infections (SSI), material-related complications, neurological complications, malunion/non-union and, reoperations performed. A forward stepwise multivariable logistic regression analysis was used to identify any risk factors associated with these complications.

Results

Complications occurred in 55 (24%) of the 233 included patients. SSIs were most common, occurring in 34 (15%) patients. Duration of surgery (odds ratio 1.01 per minute, 95% confidence interval 1.00–1.01) and obesity (odds ratio 1.10 per BMI point, 95% confidence interval 1.29–7.52) were independent risk factors for the development of SSI. Less common post-operative complications were material-related complications (8%) and neurological damage (5%).

Conclusion

Limiting operation time by using less invasive and less time-consuming surgical approaches may reduce the risk of SSI. More awareness and postoperative screening for early signs of SSI are mandatory, especially in obese patients. Future research should include large prospective patient cohorts to determine risk factors for other postoperative complications associated with pelvic fracture surgery.

Introduction

Pelvic fractures, including both pelvic ring and acetabular fractures, are often caused by high-energy trauma such as traffic accidents. They occur in up to 25% of severely injured patients [6, 22]. Pelvic fractures can have a profound impact on the patient's long-term quality of life; many patients do not fully regain their initial level of physical functioning, and experience mental health problems [5]. Often, surgical fixation of the pelvic ring and/or acetabulum is required to restore stability and improve patient outcomes [23]. Although many surgical techniques and approaches for fixation of pelvic ring and acetabular fractures are described in the literature, open reduction and internal fixation (ORIF) is still the gold standard, since it provides the best possibilities for adequate fracture reduction and fixation, as well as the best long-term results [9, 10].

Pelvic fracture surgery is associated with complication rates up to 35% [12, 16]. These complications include postoperative infections, neurological complications, re-operations, and mortality [3, 4]. Knowledge of postoperative complication rates and risk factors associated with pelvic fracture fixation is needed for the development of prevention strategies and the improvement patient outcomes [11]. Although understanding the risk factors for surgical complications is important, the available literature regarding complications after pelvic fracture surgery is heterogeneous and mostly addresses only specific subgroups of patients, fracture types, or surgical techniques [11, 20].

The current study included a cohort of patients with pelvic ring, acetabular or combined fractures that were operated on via commonly used surgical approaches. The aim of this study was to investigate the incidence of common surgical complications and identify their potential risk factors.

Methods and materials

A retrospective cohort study was conducted in two level-1 trauma centres in the Netherlands: the Leiden University Medical Center (LUMC) in Leiden and the Haaglanden Medical Center (HMC) in The Hague. The study protocol was approved by the regional Medical Ethics Review Board (protocol no. G20.118).

Patients

All adult patients (≥18 years old) with a surgically treated pelvic ring and/or acetabular fracture between January 2015 and January 2021 were selected from the regional trauma registry and included for analysis. Patients with previous pelvic ring or acetabular fractures and patients with pathological fractures were excluded.

All patients received standard care according to the current hospital's operative and postoperative treatment guidelines regarding traumatic pelvic fractures. According to these guidelines, all patients received standard antibiotic prophylaxis of 1 or 2 g of cefazolin. All operations were conducted by a senior trauma surgeon trained and experienced in pelvic fracture surgery, assisted either by another trauma surgeon or a surgical resident.

Data collection

All data were collected from electronic patient records of participating centers. Data included the number and type of complications, including surgical site infections (SSI). SSIs were defined if they were indicated as such in the patient records or if there were local signs of infection at the incision site (e.g., redness, wound fluid leakage) either combined with systemic signs of infection (e.g., fever, leukocytosis). Material-related complications were defined as hardware failure of material and mechanical irritation followed by material removal. Nerve damage was defined as persistent nerve damage after 6 months after surgery. Other study parameters included mal- and non-union, reoperation, baseline characteristics including demographic data, obesity defined as body mass index ≥ 30, ASA Physical Status Classification, smoking, osteoporosis, use of anticoagulants, fracture and other injury characteristics including high or low energy trauma, applied treatment, surgical intervention (Kocher-Langenbeck approach, Modified Stoppa approach, ilioinguinal approach, percutaneous fixation and external fixation), operation time (time between incision and wound closure), materials used, use of pre- and postoperative antibiotics, and hospital outcomes including duration of hospital stay, ICU admission and in-hospital mortality. Data were stored in a secured and coded database in the Castor Electronic Data Capture (EDC) System. Pelvic ring fractures were classified according to the Young-Burgess classification and acetabular fractures according to the Letournel classification [1, 18].

Statistical analysis

Data are presented for the total cohort and by fracture type. Categorical data were presented as number and percentage, and continuous variables were presented as mean with standard deviation (SD) or as median with interquartile range (IQR) if not normally distributed according to the Shapiro–Wilk test. Differences in the mean operation time between surgical approaches were tested using ANOVA. A forward stepwise multivariable logistic regression analysis (p-to-enter = 0.05) was used to identify risk factors for the most prevalent postoperative complication (SSI). All analyses were performed using IBM SPSS Statistic version 27.

Results

Baseline characteristics and hospital outcomes

The study population consisted of 233 patients. Baseline characteristics are presented in Table 1. The median age was 59 years (IQR 38–72), and 62% of patients were male. Seventy-seven percent of the patients had sustained high-energy trauma. Twenty-nine percent of the patients were admitted to the ICU. Six patients died during hospital admission (3% of patients). Five patients died due to injuries other than the pelvic fracture. One patient died one week after the initial operation due to a bowel perforation and one patient died because of an in-hospital cardiac arrest (**Table 1**).

Pelvic ring fractures

Pelvic ring fractures were diagnosed in 127 (55%) patients. Most common were Lateral Compression (LC) type 1 fractures (n = 37; 29%), LC type 2 fractures (n = 22; 17%) and isolated sacrum fractures (n = 19; 15%) (**Table 2**). A percutaneous surgical approach was used in 39 patients (31%) and the modified Stoppa approach in 35 patients (28%). Twenty-eight patients were treated using external fixation, of whom 22 received internal fixation and 6 external fixation as definite treatment.

Acetabular fractures

In total, 101 (43%) patients suffered from an acetabular fracture. Both-column type was seen in 29 patients (29%) and anterior posterior hemi-transverse fracture in 27 patients (27%) (**Table 2**). The modified Stoppa approach was used in 51% of patients (n = 51) and the Kocher-Langenbeck was used in 23% of patients (n = 23). Five patients received a total hip arthroplasty as a primary treatment without previous fixation (5%). Secondary hip prostheses were placed in 8 (8%) patients.

Combined fractures

Five patients (2% of the cohort) with a median age of 35 years (IQR 31–50) sustained combined pelvic ring and acetabular fractures. All these patients sustained a high-energy trauma. The modified Stoppa approach was used in 2 patients (40%), two patients were treated with a modified Stoppa combined with an ilioinguinal approach, medial lumbosacral incision or a prolonged abdominal incision (**Table 2**).

Duration of surgery

The mean duration of surgery differed significantly between the surgical approaches ($p < 0.01$). The shortest operation time was recorded for patients undergoing surgical fixation via the percutaneous approach (mean 57 ± 28 min.). The longest duration of surgery was recorded for the group in which a combination of the modified Stoppa and Kocher- Langenbeck approach was used (mean 277 ± 50min.) (**Table 3**).

Postoperative complications

Seventy postoperative complications occurred in 55 (21%) patients (**Table 4**). SSIs were observed in 34 patients, of whom 29 subsequently needed some sort of re-operation (mainly operative debridement because of SSIs). Osteomyelitis in addition to a deep infection was diagnosed twice (**Table 4**). Overall, *Staphylococcus aureus* was found in 6% of patients with an infection, and another 6% had an isolated *Staphylococcus epidermidis* in their wound culture. In 5%, an *Enterococcus faecium* and in another 5%, *Streptococcus anginosus* were found in the wound cultures. Ten percent of the patients with an infection were treated with flucloxacillin, and 7% was treated with vancomycin. Material-related complications occurred in 14 patients. Irritation due to fixation material subsequently led to osteosynthesis removal in 8 cases and plate breakage in 6 cases. Impaired fracture healing, including non-union and malunion, was diagnosed in 8 patients and eventually led to revision surgery in 6 cases. Persistent neurological complications occurred in 10 patients (**Table 4**).

Risk factors for surgical site infections (SSI)

Univariable analysis showed that patients with SSI were significantly younger (mean 56 years vs. 50 years; p = 0.09; Table 5), more often suffered from obesity (35% vs 12%; p = 0.001), had a significantly longer duration of surgery (179 min vs 138 min; p = 0.003) and hospital stay (28 days vs 17 days; p = 0.08). The use of external fixator before definitive surgery, the rate of ICU admission, smoking and high or low-energy trauma did not differ significantly between the patients with or without SSIs (**Table 5**).

In the multivariable logistic regression analysis using forward selection, presence of obesity (OR: 3.12; 95% CI: 1.29–7.52; p = 0.01) and duration of surgery (OR per minute increase: 1.01; 95% CI: 1.00–1.01; p = 0.04) were identified as independent risk factors for the development of SSI (**Table 5**).

Discussion

This cohort study found an overall complication rate following operative treatment of pelvic ring and acetabular fractures of 21% and in-hospital mortality of 3%. The most common postoperative complication were SSIs (accounting for 49% of all reported complications) followed by material-related (20%) and neurological complications (14%). Multi-variable analysis identified duration of surgery and obesity as independent risk factors for SSIs.

Surgical site infections (SSI)

In the current study, patients' age, obesity, duration of surgery, and hospital stay were significantly associated with SSI in the univariable analysis (**Table 5**). In the multivariable analysis, obesity (OR = 3.12; p = 0.01) and duration of surgery (OR =1.006; p = 0.04) remained independent, statistically significant predictors for the development of SSI after pelvic fracture surgery (**Table 3**). In pelvic fracture surgery, ORIF is still the gold standard since it provides excellent fracture exposure. The downside of open surgery, however, is the prolonged operation time and large surgical wound areas which increase the risk of SSI as shown by our study and other literature [8]. Based on these findings, avoiding prolonged operation times seems of key importance to reduce the risk of SSI. In the current study, the shortest operation time (57 ± 28 min.) was recorded in patients treated via the percutaneous approach. This approach is not only associated with shorter operation times but because of its minimally invasive nature also involves smaller surgical wound areas. However, for complex multi-fragment displaced pelvic ring or acetabular fractures, a percutaneous approach is not possible because of technical reasons, including unsatisfactory fracture exposure leading to inadequate fracture reduction or fixation. Still, further development of novel minimally invasive and efficient operation techniques is key for reducing operation time and wound exposure which would reduce the risk of postoperative infections [2]. Another significant risk factor identified in the current study was obesity. Several underlying causes such as lower tissue levels of prophylactic antibiotic and prolonged operation times are hypothesized to lead to the increased risk of SSI in obese patients [7, 13, 21]. Extra pre- and postoperative attention, adequate pre-operative counseling, about the increased risk of SSI should be considered in these patients. Furthermore, extra attention and awareness of early signs of SSI are recommended to prevent or, if present, to detect SSI in an early stage. Early detection followed by adequate treatment leads to less severe outcomes and could avoid the need for operative debridement [25, 26]. However, in the current study, almost all patients with SSI needed revision surgery, which can lead to a significantly longer hospital stay, adverse outcomes, or higher healthcare costs.

Neurological complications

Persistent neurological complications (13% of all complications) were relatively uncommon, which is in accordance with existing literature [15]. Neurological complications can either be caused by the accident itself or be induced by the intervention. In acetabular fractures, involvement of the posterior wall and the Kocher-Langenbeck approach are more commonly associated with nerve damage because the sciatic nerve is at risk [17]. This is also the case for posterior fixation of pelvic ring fractures [15]. However, when anterior pelvic ring fractures are fixated using the modified Stoppa approach, the neurovascular bundles of the bladder are particularly at risk [15]. Additionally, iatrogenic injury of the obturator and sciatic nerve has been described when using this approach [15].

Material-related complications

Although less common, material-related complications after acetabular and pelvic ring surgery are reported and associated with severe adverse outcomes including chronic residual pain, material removal, deformity, and progressive physical impairment [19, 24]. Material-related complications, including plate breakage and mechanical irritation accounted for 13% of all complications observed in the current study. Literature reporting on material-related complications after acetabular or pelvic ring treatment reports complication rates between 0 and 22% but is heterogeneous with respect to definition and included patients [3, 15].

Impaired fracture healing

Although mal- and non-union of surgically treated acetabular and pelvic ring fractures are rare, treating these conditions can be very challenging [14]. Since mal- and non-union are uncommon, literature regarding this matter is scarce, and exact incidence rates are not clearly defined. This is partly due to the differences in the definition of mal- and non-union between studies [14]. In the current study, impaired fracture healing diagnosed on radiographs occurred in 3% of the patients. Several underlying causes such as low-grade infections, osteoporosis, or other conditions involving bone demineralization are associated with the development of non- and malunions. However, most cases of mal- or non-union after pelvic fracture surgery are caused by delayed or inadequate fixation [27]. Frequent follow-up using physical examination and radiographic evaluation is necessary to detect these complication and to treat it accordingly.

Study limitations

The main limitations of the study are related to the retrospective design and its small sample size. Therefore, the statistical power was limited, and only two independent risk factors for the most common complication (SSI) could be identified in the multivariable analysis. Due to the retrospective study design and without data on follow-up after hospital discharge, it was not possible to assess the effects of complications on long-term functional outcomes.

Conclusion

The most common postoperative complications following surgery for pelvic ring or acetabular fractures are SSIs, which account for almost half of the reported complications. Independent risk factors for SSIs were increased duration of surgery and obesity. These findings stress the need to avoid prolonged operation times and encourage the use of minimally invasive surgical approaches. Furthermore, extra postoperative awareness of early signs of SSIs is recommended to prevent adverse outcomes and re-operations, especially in obese patients, since these patients are highly susceptible to developing SSIs. More prospective research is needed with larger patient cohorts including all subgroups of patients, fracture types and surgical techniques to further determine risk factors for post-operative complications associated with pelvic fracture surgery.

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Tables and figures

Table 1. Patient, injury characteristics and hospital outcomes of patients with pelvic ring, acetabular and combined fractures

	All patients n = 233	Pelvic ring fracture n = 127 (55%)	Acetabular fracture n = 101 (43%)	Combined fractures n = 5 (2%)
Patient data				
Age, median (IQR)	59 (38–72)	56 (34–72)	62 (43–72)	35 (31–50)
Male, n (%)	144 (62)	60 (47)	82 (81)	2 (40)
Obese, n (%)	35 (15)	16 (13)	16 (16)	3 (9)
Medical history; n (%)				
Chronic diseases	119 (51)	66 (52)	51 (51)	2 (40)
Previous trauma	19 (8)	9 (7)	9 (9)	1 (20)
Use of anticoagulants; n (%)	39 (17)	22 (17)	17 (17)	0 (0)
ASA physical status; n (%)				
ASA 1	43 (19)	25 (20)	17 (17)	1 (20)
ASA 2	103 (44)	57 (44)	45 (45)	2 (40)
ASA 3	67 (29)	34 (27)	32 (32)	1 (20)
ASA 4	20 (9)	12 (9)	7 (7)	1 (20)
Smoking; n (%)				
Non-smoker	152 (65)	77 (60)	74 (73)	1 (20)
Former smoker	22 (9)	14 (11)	8 (8)	0 (0)
Smoker	49 (21)	29 (23)	17 (17)	3 (60)
Osteoporosis; n (%)	33 (14)	23 (18)	10 (10)	0 (0)
Injury data				
Energy trauma; n (%)				
High energy	180 (77)	95 (75)	80 (79)	5 (100)
Low energy	53 (23)	32 (25)	21 (21)	0 (0)
Hospital outcomes				
ICU admission; n (%)	68 (29)	49 (38)	15 (15)	4 (80)
Duration of ICU admission in days, median (IQR)	2 (1–6)	2 (1–6)	1 (1–3)	4 (3–6)
Duration hospital stays in days, median (IQR)	12 (8–20)	12 (7–21)	12 (9–17)	28 (18–84)
In-hospital mortality; n (%)	6 (3)	5 (4)	1 (1)	0 (0)

IQR, interquartile range; BMI, body mass index; ASA, American Society of Anesthesiology physical status classification; ICU, intensive care unit

Table 2. Fracture classification, surgical approaches and fixation materials, by fracture type

	Pelvic ring fracture n = 127 (55%)	Acetabular fracture n = 101 (43%)	Combined fractures n = 5 (2%)
Young- Burgess classification, n (% of total)			
LC I	37 (29)		4 (80)
LC II	22 (17)		0 (0)
LC III	8 (6)		0 (0)
APC I	8 (6)		0 (0)
APC II	11 (9)		0 (0)
APC III	8 (6)		0 (0)
Vertical shear	12 (9)		1 (20)
Combined	2 (2)		0 (0)
Isolated sacrum fracture	19 (15)		0 (0)
Letournel classification, n (% of total)			
Posterior wall		11 (11)	0 (0)
Posterior column		1 (1)	0 (0)
Anterior wall		2 (2)	0 (0)
Anterior column		15 (15)	0 (0)
Transverse		3 (3)	1 (20)
Posterior column and wall		5 (5)	0 (0)
Transverse posterior wall		4 (4)	1 (1)
T-shaped		4 (4)	0 (0)
Anterior Colmn posterior hemi-transverse		27 (27)	2 (40)
Both columns		29 (29)	1 (20)
Surgical approach; n (% of total)			
modified Stoppa	35 (28)	51 (51)	2 (40)
Ilioinguinal	2 (2)	6 (6)	0 (0)
Kocher-Langenbeck	1 (1)	23 (23)	0 (0)
Percutaneous	39 (31)	0 (0)	0 (0)
Midline lumbosacral incision	7 (6)		
modified Stoppa + Ilioinguinal lateral window	4 (3)	5 (5)	1 (20)
modified Stoppa + Kocher-Langenbeck	0 (0)	9 (9)	0 (0.0)
modified Stoppa + Percutaneous	21 (17)	1 (1)	0 (0)
modified Stoppa + Medial lumbosacral incision	2 (2)	0 (0)	1 (1)
Ilioinguinal + Percutaneous	1 (1)	0 (0)	0 (0)
Total external fixator placed	28 (22)	4 (4)	0 (0)
External fixator as definite treatment	6 (5)	0 (0)	0 (0)
Other approaches*	15 (12)	6** (6)	1*** (20)

	Pelvic ring fracture n = 127 (55%)	Acetabular fracture n = 101 (43%)	Combined fractures n = 5 (2%)
Fixation material; n (% of total)			
Plate	57 (45)	96 (95)	5 (100)
Screws	93 (73)	27 (27)	3 (60)
Anterior screw fixation	30 (23)	15 (15)	2 (40)
Posterior screw fixation	1 (10)	7 (7)	0 (0)
SI-screw fixation	74 (58)	6 (6)	1 (20)
Pedicle screw fixation	6 (5)	0 (0)	0 (0)
Primary total hip prosthesis	0 (0)	5 (5)	2 (9.1)
Secondary placement of THA	0 (0)	8 (8)	0 (0)

* Other surgical approach for pelvic ring fractures: Pfannenstiel incision n = 5; Incision near the SI joint n = 2; Smith-Peterson approach n = 1; Iliofemoral approach n = 1; External fixator only n = 6
** Other surgical approach acetabular fractures: Lateral approach n = 1; Parasymphyseal approach n = 1; Smith-Peterson approach n = 1; Iliofemoral approach n = 1; Modified Gibson approach n = 1; Median laparotomy n = 1
*** Other surgical approach for combined fractures: Prolonged abdominal incision followed by a modified Stoppa n = 1

Table 3. Mean duration of pelvic fracture surgery, by surgical approach

Operative approach	Mean duration (minutes ± SD)	*p* (ANOVA)
modified Stoppa	148 (60)	<0.01
Ilioinguinal	204 (58)	
Kocher-Langenbeck	161 (62)	
Percutaneous	57 (28)	
modified Stoppa + ilioinguinal	228 (64)	
modified Stoppa + Kocher-Langenbeck	277 (50)	
modified Stoppa + percutaneous	146 (60)	

SD, standard deviation

Table 4. Postoperative complications in 55 patients with pelvic fractures

Complication type	Number of complications	Number of re-operations
Total	70	
Infection	34	29
Osteomyelitis	2	1
Material-related complications	14	11
Plate breakage	6	3
Mechanical irritation (implant removal)	8	8
Persistent neurological deficit	10	1
Non-union	7	5
Mal-union	1	1
Other	1	1

*One patient developed a paralytic ileus followed by a bowel perforation one week after initial operation. The patient required emergency surgery to repair the bowel and to shorten the acetabular screw. The complication possibly the result of the pelvic surgery or due to the initial injury

Table 5. Univariable association of patient- and fracture-related characteristics with post-operative infection in patients with pelvic fractures

	No surgical site infection (n = 199)	Surgical site infection (n = 34)	*p*-value
Age, mean (SD)	56 (20)	50 (18)	0.09
Obese, n (%)	23 (12)	12 (35)	0.001
Duration of surgery (min ± SD)	138 (74)	179 (71)	0.003
ICU admission; n (%)	58 (29)	10 (29)	0.98
Smoking; n (%)	Non-smoker: 153 (79); Smoker: 42 (21)	Non-smoker: 21 (68); Smoker: 10 (32)	0.19
Energy trauma; n (%)	High-energy: 154 (77); Low-energy: 45 (23)	High-energy: 26 (76); Low-energy: 8 (24)	0.91
External fixator before definitive surgery; n (%)	No: 179 (90); Yes: 20 (10)	No: 28 (82); Yes: 6 (18)	0.19
Surgical approach; n (%)	modified Stoppa 77 (39); KL 21 (11); Percutaneous 36 (18); Other 65 (33)	modified Stoppa 11 (32); KL 2 (6); Percutaneous 3 (9); Other 18 (53)	0.12

*All other approaches as described in Table 2

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The relation between surgical approaches for pelvic ring and acetabular fractures and postoperative complications: a systematic review

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Abstract

Introduction

Although many articles report complications after pelvic ring and acetabular fracture surgery, a general overview of complication rates and potential risk factors is still lacking. The current review provides a comprehensive summary of postoperative complications after pelvic ring and acetabular fracture surgery in relation to the surgical approach.

Material and Methods

PubMed and Embase databases were systematically searched using the keywords, pelvic fracture, acetabular fracture, fixation, surgical approaches, complications, and their synonyms. Extracted data included patient and fracture characteristics, surgical approaches, and postoperative complications: surgical site infections (SSIs), implant-related complications, mal-, and non-union. Study data were summarized using descriptive statistics.

Results

Twenty-two studies (twenty-one retrospective cohort studies, of which three comparative, and one randomized controlled trial) were included in this review. The overall complication rates reported for the included surgical approaches were: 17% for the (modified) Stoppa approach, 11% for percutaneous fixation, 5% for the Kocher–Langenbeck approach, 7% for the ilioinguinal approach and 31% for external fixation. The most frequent complications were SSI (22%) and neurological complications (31%), which were most often reported in patients treated with an external fixator. Reoperation rates were comparable for the surgical approaches (4–8%). Two studies reported on risk factors and identified concomitant traumatic injuries, prolonged ICU stay and high body mass index as risk factors for SSI.

Conclusion

External fixation of pelvic fractures is associated with the highest complications rates including SSIs and neurological complications. Although postoperative complications are frequently reported after pelvic fracture surgery, more studies are needed to identify potential risk factors. These will assist the surgeon in preoperative decision making and development of preventive strategies.

Introduction

Pelvic fractures, including pelvic ring and acetabular fractures represent a broad spectrum of injuries. Minor pelvic ring or acetabular fractures are usually the result of low-energy trauma, while major pelvic ring fractures mainly result from high-energy trauma (HET) and are diagnosed in up to 25% of young severely injured patients [1–3]. HET-related pelvic fractures are especially associated with high mortality rates of 20-50% [1–9]. In extensive or displaced acetabular fractures and in unstable pelvic ring fractures, fixation is often required to restore stability and joint congruity for acceptable long-term functional results. In patients with signs of hemodynamic instability caused by major pelvic ring and/or acetabular fractures, acute temporary stabilisation followed by a secondary definitive fixation may be needed to obtain acute hemorrhage control and to prevent exsanguination [10].

Although novel and less invasive operative techniques are emerging, open reduction and internal fixation (ORIF) remains the gold standard for those cases that cannot be percutaneously fixated, providing optimal fracture exposure and achieving the best long-term results for both acetabular and pelvic ring fractures [11]. While there are many different surgical approaches to perform ORIF, selecting the appropriate surgical approach for obtaining optimal fracture exposure is fundamental in the management of these types of fractures. In general, every surgical intervention may be associated with post-operative complications. The extent of the approach for fracture fixation of the pelvis may vary depending on the type and location of the fracture, as well as on other patient-related factors. Due to differences in anatomical location, the extent of the dissection and duration of the operation, different surgical approaches for both acetabular and pelvic ring fracture fixation pose varying risks of postoperative complications [12, 13]. These complications, including surgical site infections, may lead to impaired wound healing, hardware removal, and eventually to poor long-term functional outcomes.

Although many articles have addressed complications after pelvic ring and acetabular fracture surgery, a general overview summarizing postoperative complications by surgical approach and their potential risk factors is lacking. This systematic review aims to present a comprehensive overview of these complications in relation to specific surgical approaches for pelvic ring and acetabular fracture fixation.

Material and methods

This systematic review was conducted according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [14]. A literature search was conducted on 12 February 2022 in the online databases PubMed and Embase, using a search strategy composed in close collaboration with a trained medical librarian (**Supplementary Appendix I**). Title and abstract of the identified articles were screened using the following selection criteria: (1) adult patients (aged ≥ 18 years), (2) patients with operatively treated pelvic or acetabular fractures, (3) studies reporting on surgical complications including, but not exclusively wound complications, implant-related complications, neurological complications, (4) study size ≥ 20 patients, and (5) published in English, Dutch or German.

Case reports, studies published before 2000, studies concerning pathological fractures, primary prosthesis surgery or studies reporting on surgical approaches other than the (modified) Stoppa, minimally invasive anterior plate osteosynthesis (MIPO), ilioinguinal, Kocher–Langenbeck, percutaneous approach, pararectus, or external fixator placement were excluded. The full text of the studies meeting the inclusion criteria was read and selected if meeting the same selection criteria. Studies reporting on multiple approaches were excluded if complications were not reported per approach. Study selection and data extraction were conducted independently by two authors (RT, CM).

Data extraction

The following data were extracted from the included studies: study design, patient characteristics, trauma mechanism, fracture classification, surgical approaches, postoperative complications, and re-operations (including secondary placement of a total hip prosthesis).

Postoperative complications included surgical site infections (SSIs), implant-related complications (defined as plate and/or screw breakage and/or complaints related to osteosynthesis material), malunion (healing of the bone in an abnormal position), non-union (failure of the fractured bone to heal), and neurological complications.

Differentiation between deep and superficial infections was considered but not performed since the included articles provided insufficient information or used heterogeneous definitions. Implant-related complications, neurological complications and mal- and non-union were scored if the included studies described these as surgery-related complications. Data were divided into subgroups based on fracture type (pelvic ring or acetabulum) and surgical approach.

Assessment of risk of bias

Risk of bias was independently assessed by the two reviewers (RT, CM) using the Methodological Index for Non-Randomized Studies (MINORS) criteria [15]. For non-comparative studies, this tool includes eight methodological aspects that are scored as 0 (not reported), 1 (reported but inadequate), or 2 (reported and adequate), with a maximum score of 16. For comparative studies, the tool includes four additional criteria (maximum score 24) [15].

Data analysis

Study data were reported by fracture type and surgical approach using descriptive statistics (number with percentage, mean with standard deviation or median with range). Complication rates were calculated and displayed as percentages of the included patients across the studies by surgical approach.

Results

The literature search identified 1,396 potentially relevant articles. After screening titles and abstracts, 139 studies were selected for full-text screening. After careful reading of the full-text articles, 22 studies with a total of 1,395 patients met the inclusion criteria and were included in this review [16–37; **Figure 1**]. Twenty-one studies had a retrospective study design, of which three were comparative cohort studies [18, 24, 26]. One randomized controlled trial (RCT) was included [21]. Thirteen studies comprising 702 patients reported on postoperative complications after pelvic ring fracture surgery [16–28; **Table 1**]. Nine studies with a total of 693 patients reported on the postoperative complications after acetabular fracture surgery [29–37; **Table 2**]. Follow-up periods ranged between 6 and 68 months. The study by Iqbal et al. presented complications of two surgical approaches in acetabular fractures: the ilioinguinal approach and the Kocher–Langenbeck approach [34]. According to the MINORS criteria, the methodological quality of the included studies was poor to moderate (**Table 3**).

Postoperative complications per fracture type

Postoperative complications after surgery for pelvic ring fractures were reported in 0–59% of patients; for acetabular fractures this range was 3–25% of patients. Most postoperative complications concerned SSI, varying from 0 to 35% in patients with pelvic ring fractures [16–28] and from 0 to 8% in patients with acetabular fractures [29–37], depending on the type of fracture fixation and surgical approach (**Tables 1, 2**).

Implant-related complications such as screw malposition, plate breakage after pelvic ring surgery were reported in eleven studies ranging from 0 to 23% of patients [16–24, 26, 27]. Two studies reported implanted-related complication percentages after acetabular fracture surgery of 0% and 2% of patients [32, 35]. Postoperative neurological complications after pelvic ring surgery were reported in nine studies and ranged from 0 to 10% of patients [16–18, 21, 23, 25–28]; six studies on acetabular fracture surgery reported a range from 3 to 12% of patients [29–31, 33, 35, 37].

Non-union was reported in seven pelvic ring studies with percentages ranging from 0 to 8% of patients [16, 20, 22–26]. Three acetabular fracture studies reported non-union rates from 0 to 6% of patients [30, 34, 36]. Re-operation rates varied between 0 and 24% in patients with pelvic ring [16, 18–25, 27] and between 5 and 15% in patients with acetabular fractures [30, 32, 33, 35, 36].

Post-operative complications per surgical approach

(modified) Stoppa approach

The overall complication rate for the (modified) Stoppa approach was 17.3%. SSI was the most frequent complication, occurring in 5.5% of patients with fractures of the pelvic ring or acetabulum (**Table 4**).

Two studies described the results of a total of 85 patients undergoing pelvic ring fracture surgery via a (modified) Stoppa approach [16, 17]. In both studies, all included patients underwent plate osteosynthesis. Surgical site infections occurred in 0% and 5% of patients, implant-related complications in 0–8% (**Table 1**).

Bastian et al. reported reoperations in 10% of the included patients. Three patients needed a surgical debridement because of deep infection, one patient suffered from post-operative hematoma for which surgical evacuation was required, one patient had an abdominal wall hernia for which reconstruction was needed, and one patient had an intra-articular screw which had to be removed [16; **Table 5**]. Four studies including 171 patients with an acetabular fracture reported on complications after ORIF using a (modified) Stoppa approach [29–32]. The overall complication rate was 9–25%. SSI rates were reported in all four studies (**Table 2**). One study reported an implant-related complication in one patient (2%), who needed revision surgery due to loss of reduction of the posterior column [32]. Neurological complications were present in up to 6% of patients [30, 31, 38]. Bastian et al. reported femoral palsy in one patient which resolved spontaneously within the follow-up period of 3 years [16]. Isaacson reported femoral cutaneous palsy in two patients that both needed a lateral window, one of which subsequently resolved spontaneously within the follow-up period [30]. Sing et al. reported persistent palsies up to 3–5 months of the obturator nerve and lateral cutaneous nerve in two (6%) patients [31]. One study reported non-union in 6% of patients [30]. Re-operations rates of 8% were reported in two studies [30, 32; **Table 2**]. The main reasons to perform re-operations were operative debridement because of SSIs (n = 5 patients), revision surgery because of loss of reduction (n = 1 patient), and evacuation of postoperative hematoma (n = 1 patient) (**Table 5**).

Percutaneous approach

A total of 390 patients with a pelvic ring fracture were treated using a percutaneous approach, predominantly for screw fixation (**Table 1**). The overall complication rate for the percutaneous approach was 11.0% (**Table 4**). Five studies reported on the outcomes after sacroiliac screws [18, 20–22, 24], in one study a combination of sacroiliac screws with transpubic screws were used [19] and in one study only transpubic screws [23]. Two studies compared the results of the percutaneous approach with other surgical approaches [18, 24]. The study by Chen et al. compared the results after sacroiliac plate fixation (Group A) to sacroiliac screw fixation (Group B). In Group B two patients (7%) needed screw removal because of nerve compression leading to neurological pain [18;

Table 5]. Wenning et al. compared the results after sacroiliac screw fixations (Group A) with lumbopelvic fixation (Group B) [24]. In Group A one patient (2%) suffered from a deep infection and in five patients (11%) malposition of screws was found. All patients needed revision surgery (**Table 5**). The only RCT included in this review compared the results of percutaneous sacroiliac screw fixation with open anterior sacroiliac plate fixation. Postoperative infections were significantly more frequent seen in the control group (9%) compared to the percutaneous screw fixation group (3%) [21]. Falzarano et al. reported postoperative infections in 12% of the patients. None of the patients needed operative debridement and all infections were superficial, which were successfully treated using oral antibiotics [20]. Implant-related complications occurred most often in the study by Dekimpe et al. reporting these complications in 9% of the patients. Only one patient needed screw removal because of persistent irritation and psoas tendinitis because of a penetrating screw [19]. Re-operations were most often performed (24% of patients) in the study by Osterhoff et al. [22]. Overall, for the percutaneous approach, the main reasons to perform re-operation were implanted-related (33.4%) (**Table 5**).

External fixator placement
Four studies with a total of 116 pelvic ring fracture patients reported the outcomes after treatment with an external fixator used as definitive fixation [25–28]. The overall complication rate for the external fixator placement was 31%, predominantly caused by SSI due to pin tract infections (22%) and implant-related complications, 13% such as mispositioning of the screws of the external fixator (**Table 4**). Three studies included high-energy trauma patients, and one study included low-energy trauma patients. The study by Scaglione et al. included 37 patients receiving an external fixator as definitive treatment. In four patients, external fixation was followed by definitive internal fixation [25].

The study by Bi et al. compared the results after anterior external fixation (Group A) to modified pedicle rods (Group B) [26]. Pin tract infections were observed for six (27%) patients in Group A compared to 0% in Group B. Implant-related complications were reported for five (23%) patients in Group A and included loosening of implants with consecutive loss of fixation. Neurological complications occurred in two (9%) of the patients treated with external fixation. All neurological complications consisted of temporary lateral femoral cutaneous nerve (LFCN) palsy and resolved spontaneously without residual symptoms. The infection rate reported by Bi et al. for the group treated with an external fixator (Group A: 27%) was the second highest reported by the studies included in this review [26]. Scaglione et al. reported even more post-operative infections, all pin tract infections, in 35% of the included patients [25]. However, in most of the cases the infection was superficial and successfully treated with oral antibiotics. Only in three patients, removal of pins was necessary. Neurological complications were reported to be absent in two studies [25, 27]. The remaining studies reported neurological complications in 9% and 10% [26, 28]. In the study by Bi et al. two (9%)

patients suffered from lateral femoral nerve palsy after external fixation and Vécsei et al. reported no further specified nerve lesions in two (10%) of their patients [26, 28]. Notably, the study population included by Vécsei comprised patients with severe pelvic ring fractures and significant associated injuries. Eight patients (28.6%) died upon arrival at the hospital [28].

Kocher–Langenbeck approach

Five studies included 396 patients who underwent surgery after an acetabulum fracture via a Kocher–Langenbeck approach [33–37]. The overall complication rate ranged from 3 to 12%. For this approach, the most frequently encountered complications were neurological, documented in 2% [37], 7% [33], and 12% [35] of patients (**Table 4**). Three patients in the study by Alexa et al. suffered from peroneal-nerve palsies which resolved within three months after trauma [33]. Negrin et al. reported neurological palsies in two (12%) patients, one of which suffered from persistent weakness in sensation and Kumar et al. reported sciatic nerve palsy in two patients. Both studies did not provide further details [35, 37]. Non-union was not reported in any of the patients in two studies [34, 36]. Re-operation rates ranged between 5 and 15% [33, 35, 36] and involved operative debridement due to SSI in three patients (37.5%) and secondary placement of a total hip prosthesis in five patients (62.5%) (**Table 5**).

Ilioinguinal approach

One study reported SSI in 7% of the patients treated with a reconstruction plate via an ilioinguinal approach for acetabular fractures [34]. Other post-operative complications were not reported (**Table 2**).

Reported risk factors for post-operative complications

Possible risk factors for postoperative SSIs were identified by two of the included studies [34, 36]. Both studies reported the outcomes after surgical fixation of patients suffering from acetabular fractures. Iqbal et al. found that concomitant abdominal injuries, (odds ratio [OR] 19.3; 95% confidence interval [CI]: 0.83–1.32; $p = 0.002$), prolonged ICU stay (OR: 18.3; 95% CI: 0.88–1.22; $p = 0.002$), body mass index (OR:14.2; 95% CI: 0.91–1.32; $p = 0.003$) and prolonged operation time (OR: 9.50; 95% CI: 1.12–1.56; $p = 0.008$) were associated with increased risk for SSI [34]. Suzuki et al. also identified body mass index and ICU stay as statistically significant risk factors for post-operative SSIs after acetabular fracture surgery in univariable analysis [36].

Discussion

This systematic review provides a comprehensive overview of the literature on post-operative complications for surgical approaches that are used in acetabular and pelvic ring fracture surgery. Whenever possible, we also documented the identified risk factors for postoperative complications.

Surgical approaches for pelvic ring fractures

Comparing the overall complications rate between the included approaches, the highest overall complication percentage (31.1%) was reported in patients treated with an external fixator as definitive fixation. Most of the complications observed in these groups were SSIs (22.1%) and concerned pin tract infections (**Table 4**). The study by Scaglione et al. reported the highest number with SSI rate of 34%. However, it is important to notice that in most of the cases these SSIs were superficial and could successfully be treated with oral antibiotics. Deep infection subsequently needing removal of the external fixator pins was only necessary in three patients and no cases of osteomyelitis were reported [25; **Table 5**). In patients with complex unstable pelvic ring fractures and signs of hemodynamic instability after high-energy trauma, temporary emergency stabilisation using an external fixator is inevitable for obtaining early stabilisation of both patient and fracture [39]. However, as also illustrated in this review, external fixators are notorious for high infection rates, which is explained by the persistent port d'entree caused by the external fixator pins penetrating the skin. Still in many cases, the infections are limited to the superficial subcutaneous tissue and deep infections including osteomyelitis are rare. However, adequate pin tract hygiene, frequent inspection and reducing the period to a minimum between the emergency and definitive fixation are essential to reduce risks of SSI and help in early recognition, preventing deterioration to deep infections.

The lowest SSI rates were reported for the Kocher–Langenbeck approach (3.1%) and the percutaneous approach (4.4%) (**Table 4**). Minimally invasive surgery, using smaller incisions and percutaneous insertions of screws, inflicts less tissue damage and minimal wound exposure during surgery, leading to lower post-operative SSI rates. However, especially in complex acetabular and pelvic ring fractures, sufficient exposure may be needed to achieve adequate restoration of the joint surface and fixation of the fracture. Since minimally invasive and percutaneous techniques provide limited exposure and visualisation of the fracture, the risks of these techniques may include imperfect fracture reduction and fixation [40].

The modified Stoppa approach is currently widely used for pelvic ring and acetabular fractures and was introduced to avoid dissection of the inguinal canal, femoral artery, and external iliac vessels. This minimizes the risk of iatrogenic damage to these structures while still providing adequate fracture exposure [41]. This assumption is substantiated by the finding of the current review. For the Kocher–Langenbeck approach, a higher overall neurological complication rate of 5.2% was reported compared to the modified Stoppa approach (1.1%). Sciatic nerve damage after acetabular fractures may result from the injury itself or from iatrogenic intraoperative neurological damage especially during deep dissection when using the Kocher–Langenbeck approach [42]. The risk of damaging the sciatic nerve during surgery can be reduced by clear identification and tracing the nerve prior to the division of the external rotator muscles. However, it is important to understand that extensive dissection for identification purposes can skeletonize the sciatic nerve and thus damage its blood supply [11].

The reasons for performing re-operations differed between the included surgical approaches. For the modified Stoppa approach and external fixation, the most prevalent reason for re-operations including operative debridement were SSIs, in 69% and 100% of cases, respectively. In the studies reporting on percutaneous approach, hardware removal, or additional fixation due to implant-related, complications (malposition or loss of fixation) were the main reasons (33.4%) for re-operations (**Table 4**). The extent of re-operations due to SSI differed among the included studies from simple debridement followed by a short period of oral antibiotics to removal of fixation material with extended periods of intravenous antibiotics. Previously published studies demonstrated that re-operations in trauma patients is one of the main causes of long-term reduced functional outcomes [43, 44]. It may be assumed that the same is true for the group of patients with pelvic ring and/or acetabular fractures. The available and included studies unfortunately do not allow a quantitative substantiation of this assumption. The current literature is heterogeneous with respect to fracture characteristics, reported functional outcomes, and follow-up periods.

Associated risk factors

Reports on potentially associated risk factors for postoperative complications in pelvic fracture patients are scarce in the currently available literature. In this review, only two studies identified the following risk factors associated with one specific postoperative complication, i.e., SSIs; concomitant abdominal injuries, body mass index (BMI), prolonged ICU stay and operation time [34, 36]. The presence of concomitant (abdominal) traumatic injuries may induce extensive traumatic tissue damage, resulting in increased (internal) wound surfaces, possible port d'entrée and hematomas subsequently attributing to impaired wound healing [34]. A high BMI was also found to be a significant risk factor for developing postoperative infections. In general, obese patients have an increased risk of (peri)operative complications induced by anesthesia and surgery [45]. Wound healing problems were specifically seen in obese patients. Several underlying mechanisms such as decreased tissue oxygenation, impaired inflammatory response, and malnutrition contribute to this increased risk of wound infections [46].

Limitations

Although postoperative complications after pelvic fractures are frequently addressed in the current literature, many of the available studies are small, have a retrospective study design, and have a substantial risk of bias. Only one small study was found that reported complications after the ilioinguinal approach. Large and well-designed comparative prospective studies and randomized controlled trials are still lacking. Furthermore, only two studies in this review reported on potential risk factors for the development of postoperative SSIs and no studies reporting on risk factors for other post-operative complications were found.

Conclusion

Complications after commonly used surgical approaches for fixation of pelvic ring and acetabular fractures are frequently reported, with overall complications rates up to 31%. External fixation of the pelvic ring is associated with the highest complication rates, including mainly SSIs and neurological complications. Studies identifying potential risk factors for postoperative complications are scarce. More research is needed for a better understanding of risk factors for postoperative complications after different surgical approaches in pelvic ring and acetabular fractures. Enhanced insight into this matter can help surgeons to better understand the risks their patients are exposed to and assist in the development of preventive strategies and (pre)operative decision-making.

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Figure 1. Flowchart of article selection

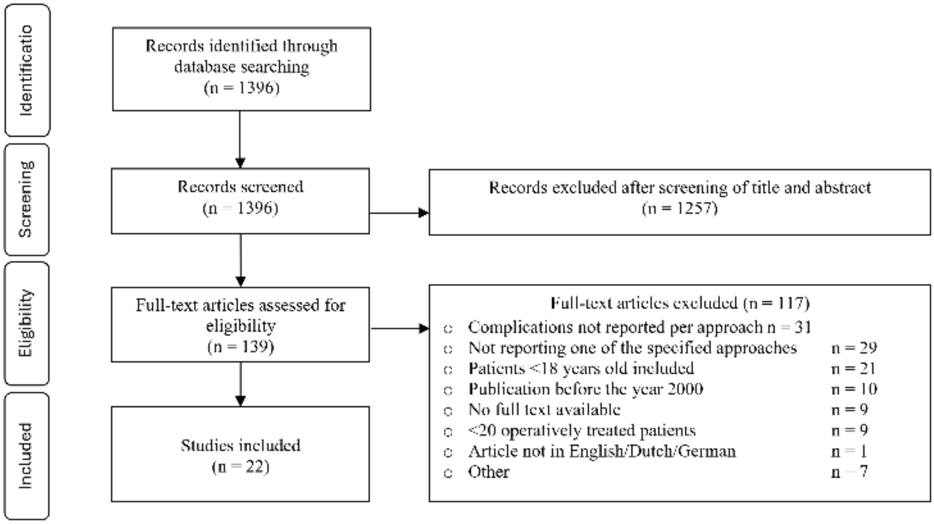

Table 1. Characteristics of studies on pelvic ring fractures per approach

Study	N*	Age**	Male %	Fracture type (%)	HET/LET#
(Modified) Stoppa approach					
Bastian et al.[16] 2016, Germany, Retrospective	63	53 (16-88)	73	Tile B2 11 Tile B3 14 Tile C1 22 Tile C2 3 Tile C3 13	NR
Oh et al. [17] 2016, Korea, Retrospective	22	41 (23-61)	45	LC12 APC 4 VS 6	High energy
Percutaneous approach					
Chen et al. [18] 2012, China, Retrospective	*Group A: 29* Group B: 29	*Group A: 37 (11)* Group B: 39 (10)	*Group A: 69* Group B: 72	Tile C1: 19 Tile C2: 8 Tile C3: 2 Tile C1: 21 Tile C2: 6 Tile C3: 2	NR NR
Dekimpe et al.[19] 2020, France, Retrospective	32	46 (24-80)	NR	Tile B 7 Tile C 23	NR
Falzarano et al. [20] 2018, Italy, Retrospective	96	37 (19–63)		Tile C 96	High energy
Li et al. [21] 2014, China, RCT.	Group A: 32 *Group B: 32*	Group A: 39(22-57) *Group B: 37.3 (21-55)*	Group A: 78 *Group B:75*	Tile C1 22 Tile C2 8 Tile C3 2 Tile C1 23 Tile C2 8 Tile C3 1	High energy High energy
Osterhoff et al. [22] 2011, Switzerland, Retrospective	25	56 (20)		LC I and LC II or Tile B2	NR
Rommens et al. [23] 2020, Germany, Retrospective	128	Median 69 (51-81)	33	FFP 1 1 (1) FFP 2 38 (30) FFP 3 11 (9) FFP 4 15 (12) Tile B 36 (128) Tile C 27 (21)	High energy 63 Low energy 65

			Complications					
Operative approach	Type of fixation	FU##	**Overall %**	**SSI %**	**Implant related %**	**Neuro-logical %**	**Non-union %**	**Re-op-eration %**
Modified Stoppa	Reconstruction plate	3.3 years (1.0-7.9)	13	5	8	2	5	10
Stoppa	Plate	16 months (10-51)	0	0	0	0	NR	NR
ORIF***	*Group A: reconstruction plate*	*23.81 Days (± 6.18)*	*0*	*0*	*0*	*0*	NR	*0*
Percutaneous	Group B: sacroiliac screws	23.94 days (± 6.03)	7	0	0	7	NR	7
Percutaneous	Sacroiliac and acetabular screws	13.5 months (4-30)	9	0	9	NR	NR	6
Percutaneous	Sacroiliac screws	NR (1 – 60 months)	12	12	0	NR	0	2
Percutaneous	Group A: Sacro iliac screws	NR	3	3	0	0	NR	3
	Group B: Control, Sacro iliac Anterior plate fixation	NR	*9*	*9*	*0*	*0*	NR	NR
Percutaneous	Sacroiliac screws	6 months (6-4)	16	0	8	NR	8	24
Percutaneous	Transpubic screws	27.6 weeks (7.0-73.5 weeks)	12	2	7	0	6	8

Study	N*	Age**	Male %	Fracture type (%)		HET/LET#
Wenning et al. [24] 2021, Germany, Retrospective Comparative	Group A: 48	Group A: 79 (14)	Group A: 17	Tile C0: 22 Tile C2: 26 Tile C3: 0		NR
	Group B: 29	*Group B: 62 (18)*	*Group B: 41*	Tile C0: 15 Tile C2: 0 Tile C3: 14		NR
External Fixator						
Scaglione et al. [25] 2010, Italy, Retrospective	41	38	51	Tile B (85) Tile C	35 6 (15)	High energy
Bi et al. [26] 2017, China Retrospective-Comparative	Group A: 22	Group A: 34 (9)	54	Tile B1: 3 Tile B2: 10 Tile B3: 9		High energy
	Group B: 21	*Group B: 38 (10.3)*		Tile B1: 5 Tile B2: 9 Tile B3:	 7	High energy
Gänsslen et al. [27] 2013, Germany Retrospective	25	79 (10)	8	Tile B	25	Low energy
Vécsei et al.[28] 2010, Austria Retrospective	20	NR	NR	NR		High energy

SSI: surgical site infection; LC: Lateral compression; APC: Anterior-posterior compression; VS: Vertical Shear; ORIF: open reduction and internal fixation; FFP: Fragility Fracture of the Pelvis; NR: Not reported
*Number of included patients
** median + range or mean + SD when no range is reported.
*** Open reduction and internal fixation using a reconstructive plate; the surgical approach was not further specified in the article.
#HET = High energy trauma, LET = low energy trauma
Reported as mean ± standard deviation or as median (IQR

			Complications					
Operative approach	Type of fixation	FU##	**Overall %**	**SSI %**	**Implant related %**	**Neuro-logical %**	**Non-union %**	**Re-op-eration %**
Percutaneous	Group A: Sacroiliac screws	At least 6 months	13	2	11	NR	0	13
Open	*Group B: Lumbo pelvic fixation*	At least 6 months	*18*	*14*	*4*	*NR*	*4*	*18*
External fixator and or sacroiliac joint fixation	External fixator: 37 External fixator + internal fixation: 4	NR	35	35	NR	0	0	7
External fixator	Group A: External fixator	16.3 months (± 2.2)	59	27	23	9	0	NR
Modified pedicle screw rod fixation	*Group B: Modified pedicle screw rod fixation*		*19*	*0*	*0*	*19*	*0*	*NR*
External fixator	External fixator	NR	12	8	4	0	NR	0
External fixator	External fixator	NR	16	10	NR	10	NR	NR

Table 2. Characteristics of studies on acetabular fractures per approach

Study	N*	Age**	Male %	Fracture type (%)	HET/LET#	Operative approach
(Modified) Stoppa approach						
Khoury et al.[29] 2012, Israel, Retrospective	60	NR	NR	NR	NR	Modified Stoppa
Isaacson et al.[30] 2014, USA, Retrospective	36	47 (16)	86	AC 1 (3) Trans 5 (14) T-type 6 (17) TPW 2 (6) ACPHT 7 (19) BC 15 (42)	High Energy	Modified Stoppa
Singh et al.[31] 2020, India, Retrospective	30	40 (18-60)	80	AC 3 (10) T-type 1 (3) TPW 1 (3) ACPHT 6 (20) BC 19 (63)	High energy	Modified Stoppa
Verbeek et al.[32] 2018, Netherlands Retrospective	45	51 (17)	71	AW 3% Trans 8% T-type 16% ACPHT 5% BC 68%	High energy 69% Low energy 31%	Modified Stoppa
Kocher-Langenbeck approach						
Alexa et al.[33] 2013, Romania, Retrospective	42	41 (26-71)	69	PW 9 (21) PC 3 (7) PCW 4 (10) Trans 11 (26) T-type 5 (12) TPW 10 (24)	High energy	KL
Iqbal et al.[34***] 2017, Pakistan, Retrospective	170	45 (22)	59	PW 70 (28) PC 32 (13) AW 8 (3) AC 18 (7) PCW 23 (9) Trans 20 (8) T-type 13 (5) TPW 7 (3) ACPHT 5 (2) BC 54 (22)	NR	KL
Negrin et al.[35] 2010, Austria, Retrospective	27	A: 40 (10) B: 42 (20)	41	Trans 27	NR	KL

					Complications			
Type of fixation	FU ##	**Overall %**	**SSI %**	**Implant related %**	**Neuro-logical %**	**Non-union %**	**Re-operation %**
Plate and/or screws	NR	25	5	NR	0	NR	NR
Plate and/or screws	32 months (9-59)	17	8	NR	6	6	8
Plate and/or screws	6 months (NR)	17	3	NR	6	NR	NR
Plate and/or screws	59 months (12-165)	9	4	2	NR	NR	8
Plate and (non-specified) screws: 39 (non-specified) Screws only: 3	NR (1-4 years)	9	2	NR	7	NR	5
Reconstruction plate	At least 12 months (NR)	5	3	NR	NR	0	NR
Plate osteosynthesis	9 months (± 6)	12	0	0	12	NR	15

Study	N*	Age**	Male %	Fracture type (%)		HET/LET#	Operative approach
Suzuki et al. [36] 2009, USA, Retrospective	157	43 (18)	77	PW PC AW AC PCW Trans T-type TPW ACPHT BC	78 7 1 29 16 29 35 48 21 69	NR	KL
Kumar et al. [37] 2021, India Retrospective	80	43 (13)	60	PW PC PCW Trans T-type TPW ACPHT	27 (34) 16 (20) 9 (11) 7 (9) 9 (11) 7 (9) 5 (6)	High Energy	KL
Ilioinguinal approach							
Iqbal et al.[34]*** 2017, Pakistan, Retrospective	45	45 (22)	59	PW PC AW AC PCW Trans T-type TPW ACPHT BC	70 (28) 32 (13) 8 (3) 18 (7) 23 (9) 20 (8) 13 (5) 7 (3) 5 (2) 54 (22)	NR	Ilioinguinal 45

SSI: surgical site infection; KL: Kocher-Langenbeck; AC: Anterior collum; AW: Anterior Wall; ACPHT: Anterior column posterior hemi transverse; BC: Both columns; PW: Posterior wall; PC: Posterior column; PCW: Posterior column + wall; Trans: Transverse type; T-Type: T-shape type; TPW: Transverse posterior wall; NR: not reported.

* Number of included patients
** median + (range) or mean + (SD).
# HET = High energy trauma, LET = low energy trauma
Reported as mean ± standard deviation or as median (IQR)
***This study is mentioned twice; once for the Kocher-Langenbeck approach and once for the ilioinguinal approach

		Complications					
Type of fixation	FU ##	**Overall %**	**SSI %**	**Implant related %**	**Neuro-logical %**	**Non-union %**	**Re-operation %**
Plate and/or screws	NR	5	5	NR	NR	0	5
Plate and/or screws	mean 2.6 years (SD)	3	1	NR	2	NR	NR
Reconstruction plate	At least 12 months (NR)	7	7	NR	NR	NR	NR

Table 3. Methodological quality assessment according to the MINORS criteria (0: not reported; 1: reported but inadequate; 2: reported and adequate)

Study	Aim of the study	Inclusion of consecutive patients	Prospective collection of data	Endpoint appropriate to the study aim	Unbiased evaluation of endpoints	F/U period appropriate to the major endpoint	Loss to F/U not exceeding 5%	Sample size calculation	Adequate control group
Bastian et al.[16]	2	1	0	2	0	2	2	1	NA
Oh et al. [17]	2	2	0	2	0	2	1	1	NA
Chen et al. [18]	2	2	0	2	0	2	2	1	0
Dekimpe et al.[19]	2	1	0	2	0	2	2	1	NA
Falzarano et al. [20]	1	0	0	2	0	2	0	0	NA
Li et al. [21]	2	2	2	2	1	2	2	1	2
Osterhoff et al. [22]	2	1	0	2	0	1	0	1	NA
Rommens et al. [23]	2	1	0	2	0	1	0	0	NA
Wenning et al. [24]	2	2	2	2	0	2	1	0	1
Scaglione et al. [25]	1	1	0	2	0	0	0	0	NA
Bi et al. [26]	2	1	0	2	0	2	2	0	0
Gänsslen et al. [27]	2	1	0	2	0	1	0	1	NA
Vécsei et al.[28]	2	0	0	2	0	0	0	0	NA
Khoury et al.[29]	0	0	0	1	0	0	0	0	NA
Isaacson et al.[30]	2	2	0	2	0	2	0	0	NA
Singh et al.[31]	2	2	1	2	0	2	1	0	NA
Verbeek et al.[32]	2	1	0	2	0	2	0	1	NA
Alexa et al.[33]	2	1	0	2	0	2	0	0	NA
Iqbal et al.[34]	2	1	0	2	0	2	1	1	NA
Negrin et al. [34]	1	2	0	2	0	2	0	1	NA
Suzuki et al. [36]	2	2	1	2	0	0	0	1	NA
Kumar et al. [37]	2	1	1	2	0	2	2	0	NA

NA: not applicable
NA: not applicable

Additional criteria			
Contemporary groups	Baseline equivalence of groups	Adequate statistical analyses	Total score
NA	NA	NA	10/16
NA	NA	NA	10/16
2	2	1	16/24
NA	NA	NA	10/16
NA	NA	NA	5/16
2	2	1	21/24
NA	NA	NA	7/16
NA	NA	NA	6/16
1	1	2	16/24
NA	NA	NA	4/16
2	2	1	14/24
NA	NA	NA	7/16
NA	NA	NA	4/16
NA	NA	NA	1/16
NA	NA	NA	8/16
NA	NA	NA	10/16
NA	NA	NA	8/16
NA	NA	NA	7/16
NA	NA	NA	9/16
NA	NA	NA	8/16
NA	NA	NA	8/16
NA	NA	NA	10/16

3

Table 4. Postoperative complications by surgical approach

	Overall complications, %	SSI, %	Implant related, %	Neurological, %	Non-union, %	Re-operations, %
(Modified) Stoppa approach	17.3	5.5	4.6	2.5	7.2	5.2
Percutaneous (Screw)	11.0	4.4	4.4	1.1	3.3	7.5
External fixator	31.1	22.1	12.9	31.0	0	4.3
Kocher Langebeck approach	5.4	3.1	0	5.2	0	6.2
Illioinguinal approach	7.0	7.0	NR	NR	NR	NR

SSI: Surgical site infections; NR: not reported

Table 5. Reasons for re-operation, by surgical approach

Study	SSI, n (%)	Implant related, n (%)	Neurological complications, n (%)	Non-union, n (%)	Additive fixation, n (%)	Hematoma, n (%)	Secondary placement THP, n (%)	Other, n (%)	Specification
(Modified) Stoppa									
Bastian et al.	3 (50)	1* (16.7)				1 (16.7)		1** (16.7)	*Intra-articular screw **Abdominal wall hernia
Isaacson et al.	3 (100)								
Verbeek et al.	2 (50)					1 (25)		1* (25)	*Revision surgery due to loss of reduction
Overall, n (%)	***13 (69.2)***	***1 (7.7)***				***2 (15.4)***		***1 (7.7)***	
Percutaneous approach									
Chen et al.			2 (100)						Screw replacement due to neurological complication
Dekimpe et al.			2 (100)						Screw removal due to irritation
Falzerano et al.		2 (100)							Screw removal due to mobilization of material
Li et al.	1 (100)								
Osterhoff et al.			2* (33.3)	2 (33.4)	2 (33.3)				*Nerve irritation
Rommens et al.	2 (25)	2* (25)		1 (12.5)		1 (12.5)		2** (25)	*Malposition of screws ** infection and non-union
Wenning et al. al.	1 (16.7)	5* (83.3)							*Mal position of screws
Overall, n (%)	***4 (14.8)***	***9 (33.4)***	***6 (22.2)***	***3 (11.1)***	***2 (7.4)***	***1 (3.7)***		***2 (7.4)***	
External fixatior									
Scaglione et al.	3 (100)								
Overall, n (%)	***3 (100)***								

Study	SSI, n (%)	Implant related, n (%)	Neurological complications, n (%)	Non-union, n (%)	Additive fixation, n (%)	Hematoma, n (%)	Secondary placement THP, n (%)	Other, n (%)	Specification
Kocher Langenbeck									
Alexa et al.	1 (50)						1 (50)		
Negin et al.							4 (100)		
Susuki et al.	2 (100)								
Overall, n (%)	***3 (37.5)***						***5 (62.5)***		

SSI: Surgical site infections; THP: total hip prosthesis.

Supplementary materials

Supplementary Appendix I. Search term for literature search

Pubmed search term:
((“pelvic ring fractures”[tw] OR “pelvic ring fracture”[tw] OR “acetabular fractures”[tw] OR “acetabular fracture”[tw] OR “acetabulum fractures”[tw] OR “acetabulum fracture”[tw] OR “pelvic fractures”[tw] OR “pelvic fracture”[tw] OR “pelvis fractures”[tw] OR “pelvis fracture”[tw] OR ((“Fractures, Bone”[majr] OR “fracture”[ti] OR “fractures”[ti] OR “fractured”[ti] OR “fracturing”[ti] OR “fractur*”[ti]) AND (“Acetabulum”[majr] OR “Pelvic Ring”[ti] OR “Pelvic Rings”[ti] OR “Pelvis Ring”[ti] OR “Acetabulum”[ti] OR “Acetabular”[ti] OR “Acetabul*”[ti])) OR (“Fractures, Bone”[majr] AND (“Pelvic Bones”[majr] OR “Pelvis”[majr] OR “Acetabulum”[majr])) OR ((“Fractures, Bone”[majr] OR “fracture”[ti] OR “fractures”[ti] OR “fractured”[ti] OR “fracturing”[ti] OR “fractur*”[ti]) AND (“Pelvic Bones”[majr] OR “Pelvis”[majr] OR “Acetabulum”[majr] OR “Pelvic Ring”[ti] OR “Pelvic Rings”[ti] OR “Pelvis Ring”[ti] OR “Pelvic”[ti] OR “Pelvis”[ti] OR “pelvi*”[ti] OR “Acetabulum”[ti] OR “Acetabular”[ti] OR “Acetabul*”[ti]))) AND (“Young and Burgess”[tw] OR “young burgess”[tw] OR (“Young”[tw] AND “Burgess”[tw]) OR “Tile’s classification”[tw] OR “Tile classification”[tw] OR “Tile”[tw] OR “Rommens”[tw] OR “letournel”[tw] OR “Trauma mechanism”[tw] OR “Trauma mechanisms”[tw] OR “High Energy”[tw] OR “Accidents”[Mesh] OR “Accidental Falls”[Mesh] OR “Fall”[tw] OR “falls”[tw] OR “falling”[tw] OR “accidents”[tw] OR “accident”[tw] OR “crash”[tw] OR “crashes”[tw] OR “crashed”[tw] OR “collision”[tw] OR “collisions”[tw] OR “collisioned”[tw] OR “accidental”[tw] OR “trauma”[ti] OR “traumas”[ti] OR “traumatic”[ti] OR “Risk Factors”[mesh] OR “risk factor”[ti] OR “risk factors”[ti]) AND (“Postoperative Complications”[majr] OR “Pain, Postoperative”[majr] OR “Postoperative Cognitive Complications”[majr] OR “Postoperative Hemorrhage”[majr] OR “Prosthesis-Related Infections”[majr] OR “Surgical Wound Dehiscence”[majr] OR “Surgical Wound Infection”[majr] OR “postoperative complications”[tiab] OR “postoperative complication”[tiab] OR “post operative complications”[tiab] OR “post operative complication”[tiab] OR “peroperative complications”[tiab] OR “peroperative complication”[tiab] OR “per operative complications”[tiab] OR “per operative complication”[tiab] OR “perioperiative complications”[tiab] OR “perioperiative complication”[tiab] OR “peri operiative complications”[tiab] OR “peri operiative complication”[tiab] OR “Intraoperative Complications”[majr] OR “Intraoperative Complications”[tiab] OR “Intraoperative Complication”[tiab] OR “Intra operative Complications”[tiab] OR “Intra operative Complication”[tiab] OR “medical complications”[tiab] OR “medical complication”[tiab] OR “wound complications”[tiab] OR “wound complication”[tiab] OR “Wound Infection”[majr] OR “Wound Infections”[tiab] OR “Wound Infection”[tiab] OR “leak”[tiab] OR “leaks”[tiab] OR “leaking”[tiab] OR “Hemorrhage”[majr:NoExp] OR “haemorrhages”[tiab] OR “haemorrhage”[tiab] OR “haemorrhaging”[tiab] OR “hemorrhages”[tiab] OR “hemorrhage”[tiab] OR “haemorrhaging”[tiab] OR “bleeding”[tiab] OR “bleed”[tiab] OR “bleeds”[tiab] OR “Hematoma”[majr] OR “Hematoma”[tiab] OR “Hematoma”[tiab] OR “Haematoma”[tiab] OR “Haematoma”[tiab] OR “material complications”[tiab] OR “material complication”[tiab] OR “Surgical Equipment/adverse effects”[majr] OR “outbreak of material”[tiab] OR “neurogenic complications”[tiab] OR “neurogenic complication”[tiab] OR “Chronic Pain”[majr] OR “Chronic Pain”[tiab] OR “Chronic Pains”[tiab] OR “nerve damage”[tiab] OR “nerve injuries”[tiab] OR “nerve injury”[tiab] OR “Peripheral Nerves/injuries”[majr] OR “Nervous System/injuries”[majr] OR “Neurological damage”[tiab] OR “Neurologic damage”[tiab] OR “Neurological injuries”[tiab] OR “Neurologic injuries”[tiab] OR “Neurological injury”[tiab] OR “Neurologic injury”[tiab] OR “Reoperation”[majr] OR “Reoperation”[tiab] OR “Reoperations”[tiab] OR “Re operation”[tiab] OR “Re operations”[tiab] OR “Repeat Surgery”[tiab] OR “Revision Surgery”[tiab] OR “Hospital Mortality”[majr] OR “Hospital Mortality”[tiab] OR “Inhospital Mortality”[tiab] OR “Mortality”[majr] OR “Mortality”[tiab] OR “deaths”[tiab] OR “death rate”[tiab] OR “death rates”[tiab] OR “secondary total hip”[tiab] OR “secondary hip”[tiab] OR “secondary tha”[tiab] OR “secondary thr”[tiab] OR “Fractures, Bone/mortality”[majr] OR “infection”[tiab] OR “infections”[tiab] OR “infected”[tiab] OR “Surgical Procedures, Operative/complications”[majr] OR “complications”[ti] OR “complication”[ti]) NOT ((“Infant”[mesh] OR “Child”[mesh] OR “Adolescent”[mesh] OR “Infant”[ti] OR “Child”[ti] OR “Adolescent”[ti] OR “Infants”[ti] OR “Children”[ti] OR “Adolescents”[ti] OR “Infancy”[ti] OR “Childhood”[ti] OR “Adolescence”[ti] OR “pediatric”[ti] OR “paediatric”[ti] OR “pediatrics”[ti] OR “paediatrics”[ti]) NOT (“Adult”[mesh] OR “adult”[ti] OR “adults”[ti] OR “elderly”[ti])) AND (“1990/01/01”[PDAT] : “3000/12/31”[PDAT]) AND (“English”[la] OR “Dutch”[la] OR “German”[la]) NOT ((“Case Reports”[ptyp] OR “case report”[ti]) NOT (“Review”[ptyp] OR “review”[ti] OR “Clinical Study”[ptyp] OR “trial”[ti] OR “RCT”[ti])))

Embase search term:
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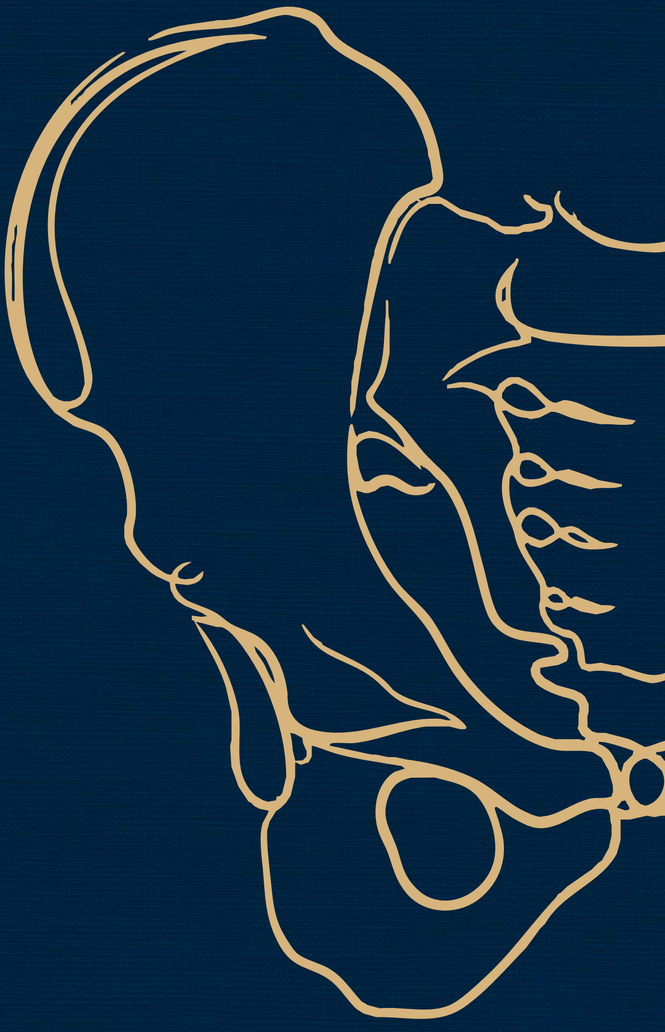

Part II

Treatment strategies for pelvic ring fractures in elderly patients

4

Indications for surgical fixation of low-energy pelvic ring fractures in elderly: a systematic review

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Abstract

Introduction

There are no generally accepted criteria for when and how to fixate osteoporotic pelvic ring fractures in elderly patients. This systematic review aims to summarize the currently available literature regarding the indications and methods for surgical fixation of fragility fractures of the pelvic ring in elderly patients after low-energy trauma.

Materials and methods

The PubMed and Embase databases were searched using the keywords: pelvic fractures, geriatric, fragility, osteoporosis, and surgical fixation, and their synonyms. Extracted data, including the indication, method of operative fixation, and postoperative outcomes (pain levels, mobility, complications, and mortality) were analyzed using descriptive statistics. The studies were too heterogeneous to perform a meta-analysis.

Results

Eleven cohort studies (three comparative and eight noncomparative) were included. The methodological quality was poor to moderate; the studies were heterogeneous regarding study design and reported outcomes. In all included studies, operative treatment for all fracture types was preceded by a period of conservative treatment, comprising physiotherapy-guided full weight-bearing. Time to surgery differed widely. For posterior ring fixation, the majority of the included studies used minimally invasive surgery with transiliac-transsacral or iliosacral screws. Five studies described a form of additional fixation of the anterior pelvic ring but did not report the indications.

Conclusions

Fixation of low-energy pelvic ring fractures in elderly patients is commonly performed after a period of conservative treatment, with persistent pain as the most frequent indication for fixation. Fracture classification based on stability seems to be of secondary importance. The timing for surgical fixation of the pelvic ring fracture in elderly patients remains diverse. Large, well-designed comparative prospective studies and randomized controlled trials are needed to provide clearly substantiated guidelines.

Introduction

The incidence of osteoporotic pelvic ring fractures is increasing due to the ageing population [1, 2]. In contrast to younger patients, pelvic ring fractures in elderly patients are often the result of a low-energy fall and are rarely associated with hemodynamic instability or severe injuries to the pelvic organs or the surrounding soft tissues [1, 3, 4]. A growing number of studies regarding fracture characteristics, classifications, and treatment algorithms for osteoporotic pelvic ring fractures are being published [5–8]. However, indications for when to perform operative fixation in this frail patient group that is susceptible to perioperative and postoperative complications are not clearly defined, remain controversial and are merely based on expert opinion [5, 9–13].

Routine CT scan evaluation reveals that in up to 80% of the elderly patients, an anterior pelvic ring fracture is accompanied by a posterior fracture in the pelvic ring [7, 14]. Combined anterior and posterior pelvic ring fractures may be considered (partially) unstable and tend to be associated with higher pain levels that may inhibit early mobilisation [15, 16]. Since early mobilisation and weight-bearing are crucial in this population, surgical fracture fixation may outweigh the potential risks associated with operative treatment [15]. Still, the majority of patients with osteoporotic pelvic ring fractures are treated nonoperatively, with mobilisation guided by pain levels and adequate analgesia. The development of better perioperative imaging and the availability of minimally invasive fixation techniques have contributed to a more positive attitude towards operative treatment, especially in elderly patients with a low-energy pelvic ring fracture. Selected patients, especially those who suffer from persistent pain or unstable fractures, may benefit substantially from surgical stabilisation of the pelvic ring to gain pain reduction, and facilitate early weight-bearing. However, scientific substantiation for this suggestion remains limited and scattered.

This systematic review aims to summarize the currently available literature regarding the indications and methods for surgical fixation of fragility fractures of the pelvic ring (FFP) in elderly patients after low-energy trauma.

Methods

A systematic review of the current literature was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [17].

Search strategy

The search terms used to search the electronic databases PubMed and Embase were composed in close collaboration with a trained librarian and included the following keywords and their synonyms: pelvic fractures, geriatric, fragility, osteoporosis, and surgical fixation. The search strategy is presented in **Supplemental Appendix I**.

4

Study selection
The study selection was performed independently by two authors (RT, SV). The title and abstract of the identified studies were screened using the following criteria: (1) Clinical studies; (2) including elderly patients (age > 65 years) suffering from a fragility fracture of the pelvic ring; (3) who underwent surgical fixation of the pelvic ring; and (4) published in English or Dutch were considered for inclusion in this review. Potentially eligible full-text papers were reviewed and selected for inclusion if they met the same criteria and reported the following information: (5) type of surgical fixation; (6) indication for surgical fixation; and (7) postoperative outcomes (pain scores, mobility, complications, and/or mortality). Additionally, the reference lists in the selected articles were screened for any relevant studies that were missed in the search.

Data extraction and reporting
The following study characteristics were extracted from the selected full-text papers: author, year of publication, country, study design, number of patients, mean age, gender, fracture type and mean duration of follow-up (mean ± SD or median and range). The type of surgical fixation and the indication for operative fixation were extracted, as well as the following patient outcomes: pain levels after surgery, mobility after surgery, mortality, and complication rates. Extracted data were presented using descriptive statistics. No meta-analysis was performed for outcome data, as the studies were too heterogeneous.

Assessment of risk of bias
The risk of bias in the selected studies was independently assessed by two authors (RT and SV) using the Methodological Index for Non-Randomized Studies (MINORS) criteria. For non-comparative studies, this tool includes eight methodological aspects that are scored as 0 (not reported), 1 (reported but inadequate) or 2 (reported and adequate), with a maximum score of 16. For comparative studies, the tool includes four additional criteria (maximum score 24) [18].

Results
The literature search resulted in 438 potentially relevant studies. Twenty-six studies were selected for full-text screening. Eleven studies met the inclusion criteria and were included in this review. The process of study selection is shown in **Figure 1**.

Three retrospective cohort studies had a comparative design. One of these compared the outcomes of a non-surgical and a surgical treatment group, another compared non-surgically treated patients with a mixed group of conservatively and operatively treated patients, and one study particularly focused on comparing the outcomes of FFP I/II (stable) versus FFP III/IV (unstable) fracture types after either non-surgical or surgical treatment [19–21; **Table 1**]. The remaining eight studies were non-comparative cohort studies, addressing the indications for, and outcomes after, either isolated posterior fixation (one prospective and two retrospective cohort studies) [22–24; **Table 2**] or a combined anterior and posterior fixation (five retrospective cohort studies) [25–29; **Table 3**]. The mean age of the included patients per study ranged from 70 to 84 years. Mean follow-up varied between 4 weeks and 62 months.

Methodological quality

According to the MINORS criteria, the methodological quality of the selected studies was low to moderate (**Table 4**). The MINORS scores for the three included comparative studies ranged between 13 and 17 and for the remaining non-comparative studies between 5 and 11. All except one study had a retrospective study design. None of the studies reported a sample size calculation, or whether the endpoint assessment was unbiased.

Comparative cohort studies

Three comparative retrospective cohort studies were included in this review (**Table 1**). Osterhoff et al. compared two groups with a mean age of 81 years (range 60–98): group 1 received non-operative treatment only (n = 82), and group 2 received nonoperative treatment followed by operative treatment if the patient was unable to mobilise after 3–5 days (n = 148, of which 60 received operative treatment and 88 did not) [20]. Surgical fixation in group 2 was performed using trans-iliosacral screw fixation. Majeed mobility scores and the one-year mortality rates did not differ between the two groups. In-hospital complications occurred significantly more often in group 2.

The study by Walker et al. included 41 patients with isolated sacral fractures and a mean age of 78 years in both groups [21]. They excluded patients with an absolute operative indication because of an unstable fracture. All included patients were treated conservatively for an unspecified period, and surgery was indicated if patients were unable to ambulate or experienced severe pain during mobilisation. At hospital discharge, the 16 operatively treated patients had significantly greater reduction in pain scores compared to the conservatively treated group of 25 patients (operative: –3.9 points on a 0–10 scale; nonoperative: –0.6 points; $p < 0.01$). All patients who underwent surgical fixation were ambulatory at discharge compared to 72% of the conservatively treated patients ($p < 0.03$).

Hotta et al. compared patients suffering from stable (FFP I/II, n = 53) versus unstable pelvic ring fractures (FFP III/ IV, n = 31) with a mean age of 84 years [19]. Primarily, all patients were treated nonoperatively. If they were unable to ambulate after 10 days of conservative treatment; comprising physiotherapy-guided full weight-bearing and adequate analgesics, fixation of the posterior pelvic ring was indicated and performed using iliosacral and/or trans-sacral screws. Eight patients (FFP I/II: 6; FFP III/IV: 2) underwent surgical fixation, the remaining 76 patients (FFP I/II: 47; FFP III/IV: 29) did not. The change in functional outcomes according to the Graham scale did not differ between the FFP I-II and FFP III-IV groups (FFP I-II: 0.25 vs. FFP III-IV: 0.23, $p = 0.89$). Functional outcomes after surgical and non-surgical regimes were not reported or compared. No complications occurred after surgical fixation.

Non-comparative studies

All eight non-comparative studies reported "failure of conservative treatment" as the indication for surgical fixation of the pelvic ring (**Tables 2, 3**). Failure of conservative treatment was defined as the patient being unable to mobilise due to persistent pain. The mean time until failure of conservative treatment differed between these studies and ranged from 3 to 241 days after trauma (**Table 5**). Schmerwitz et al. followed a slightly different indication for operative treatment. They specifically described the presence of an unstable fracture (FFP III/IV) or an FFP II type, combined with persistent pain after conservative treatment (including full weight-bearing if possible), as an indication for surgical fixation of the pelvic ring fracture [22; **Table 5**].

Method of posterior ring fixation

For posterior ring fixation, the majority of the included studies used minimally invasive surgery with trans-iliosacral screws [20, 21, 24–29]. Complication rates ranged from 0 to 46%. Hospital-acquired infections (e.g. urinary tract or pulmonary infection) were frequently reported, with rates up to 34%. Surgical site infections and secondary screw loosening were seen less often, with rates up to 13% and 18%, respectively. The one-year mortality rates ranged from 12.5 to 18.5% (**Tables 1, 2, 3**).

One of the included studies performed a posterior fixation combined with cement augmentation to prevent secondary screw dislocation. Schmitz et al. used a cement-augmented transiliac internal fixator (caTIFI) [28]. All screws were placed using intraoperative fluoroscopy. No cement leakage was reported; however, in five of the 15 included patients, malposition of screws was documented on the post-operative CT scan. None of the patients required a second operation. Follow-up on pain and mobility scores was not reported [28; **Table 3**].

Schmerwitz et al. performed a minimally invasive locking-compression-plate fixation of the posterior pelvic ring in 53 patients suffering from FFP III/IV or FFP II type pelvic fractures with persistent pain after a period of conservative treatment [22]. Complications directly related to the surgery were reported in 13% of the patients. Pain levels and IOWA pelvic ring scores (including mobility levels and daily activities) upon hospital discharge were found to be satisfactory (**Table 2**). Obid et al. described the results after fixation of the posterior pelvic ring using minimally invasive lumbopelvic fixation in 13 patients [23]. All patients were operated on after failure of conservative treatment, after approximately two weeks. Surgical complications were reported in 15% of the patients. Pain and mobility scores after surgery were significantly improved when compared to preoperative levels (**Table 2**).

Method of anterior ring fixation

Six of the included studies performed additional fixation of the anterior pelvic ring, using different techniques [20, 25–29]. Plate fixation of the symphysis or of the rami only was described in three studies [20, 27, 29]. Trans-pubic or supra-acetabular screw fixation was performed in three studies and external fixators were placed in two studies [20, 26–28]. Ferry et al. performed additional anterior fixation in their study; however, the technique or approach used was not described [25]. The indication to perform anterior fixation in addition to posterior fixation was only described in one of the included studies. In the comparative study by Osterhoff et al., anterior plate fixation or an anterior subcutaneous internal fixator (INFIX) was performed if patients had a displaced fracture of the superior or inferior pubic ramus (>1 shaft width) and persistent pain over the anterior pelvic ring [20].

Discussion

The purpose of this study was to systematically describe the indications for surgical fixation of pelvic ring fractures in elderly patients following low-energy trauma.

Although slowly, the body of literature concerning when and how to operate pelvic ring fractures resulting from low-energy trauma in elderly patients is growing. The current review presents results that suggest a consensus about the indication for fixation of these fractures. In none of the included studies were the low-energy pelvic ring fractures operated on immediately after trauma; surgery was always preceded by a period of conservative treatment.

In general, patients who suffered from persistent pain and were therefore unable to mobilise after a period of supervised weight-bearing were selected for surgical fixation of the pelvic ring. Duration of the conservative treatment period differed widely. Performing immediate surgical fixation can lead to overtreatment, inducing unnecessary risks related to surgery. On the other hand, if surgery is postponed for an extended conservative period, the most painful period of healing has passed, and some patients will be undertreated. Furthermore, none of the studies included a frailty index and therefore it was not possible to assess its impact on whether to perform surgical fixation. In our opinion, this is remarkable since for this population frailty could affect the decision whether to proceed with surgical intervention. The findings of the current review are partially in line with earlier published recommendations by Rommens et al. and Oberkircher et al., who advised conservative treatment for undisplaced stable fractures (FFP I/II) and immediate surgical fixation for unstable displaced fractures (FFP III/IV), based on their extensive clinical experience [5, 8]. When conservative treatment fails, meaning that the patient is experiencing immobilizing pain, both studies recommend repeating diagnostic imaging (fluoroscopic and CT scan evaluation) and considering surgical fixation. Remarkably, Hotta et al. found in comparing the results of stable fractures (FFP I/II) and instable fractures (FFP III/IV) that after all patients had been admitted to a conservative treatment period of ten days, only eight of the 84 patients (FFP I/II: 6/53; FFP III/IV: 2/31) were unable to stand and therefore underwent surgery [19]. The remaining 76 patients (FFP I/II: 47/53; FFP III/IV: 29/31) were treated nonoperatively. At follow-up, no significant difference in mobility between the FFP I/II and FFP III/IV groups was reported. This raises the question whether immediate surgical fixation of FFP III/IV fractures is warranted [5, 8].

Five studies in the current review described a form of additional fixation of the anterior pelvic ring. Only Osterhoff et al. stated a clear indication for performing this additional fixation. They performed anterior fixation of the pelvic ring simultaneously with trans-iliosacral screws if the fracture of the superior or inferior pubic ramus was displaced by more than one shaft width and/or the patient suffered from persistent anterior pain [20]. Recently, Rommens et al. published two studies presenting the surgical options for anterior fixation but did not provide a clear indication for when to additionally fixate the anterior ring [13, 30].

Intraoperative stability testing using fluoroscopy may be useful to help in deciding whether to perform additional anterior fixation. This technique, which enables the surgeon to assess pelvic ring stability, was found to be promising for determine the need for fixation of undisplaced LC-1 type fractures in younger patients [31]. It may also be used in elderly patients to assess the stability of the pelvic ring after the initial posterior fixation. If displacement of the anterior pelvic ring fracture is observed under stress on fluoroscopy, indicating possible persistent ring instability, anterior fixation can be considered and performed during the same session.

However, the amount of applied force and the visual estimation of displacement during fluoroscopic examination are both subjective, and therefore difficult to quantify, and may differ significantly between surgeons [32]. Furthermore, if anterior ring movement is observed under compression or distraction, does that necessarily indicate instability, and how much movement should be considered clinically relevant? This limitation should be considered when using this technique, and more reproducible data would be helpful before adopting it as a standard tool in decision-making for pelvic fracture treatment.

The studies included in this review described different fixation techniques with comparable outcomes regarding postoperative infections and secondary screw loosening. The transiliac screw fixation seemed the preferred fixation technique for fractures of the posterior pelvic ring and was used in eight of the eleven included studies. The anterior pelvic ring was fixated using plate osteosynthesis in three studies and two studies used transpubic screws. The osteoporotic bone in elderly patients can be challenging in terms of achieving adequate purchase, with higher risk of secondary screw loosening [33]. For this reason, one of the included studies used cement-augmented posterior screw fixation, after which no secondary screw loosening was reported. According to the same principle used in for example, humeral head screw fixation, cement augmentation using a minimal amount of cement at the tip of iliosacral screws can increase anchorage strength and reduce the risk of secondary screw loosening [34]. Caution should be taken regarding the amount of cement used, because the use of large quantities can lead to cement leakage, with consequent adverse effects [35–37]. When fully treated transiliac–transsacral screws are placed, there is no indication for cement, since correctly placed fully threaded screws ending in the contralateral iliac bone usually have satisfactory grip. Fully threaded screws provide superior biomechanical stability and are preferred over partially threaded transiliac–transsacral or trans-iliosacral screws [38, 39].

Conclusion

The current review shows that fixation of low-energy pelvic ring fractures in elderly patients is commonly performed after a period of conservative treatment, with persistent pain as the most frequent indication for fixation. Fracture classification based on stability seems to be of secondary importance. Timing and other indications for surgical fixation of the pelvic ring fracture among elderly patients remain diverse. However, these findings are mainly based on observational non-comparative retrospective cohorts. Clear indications for when, who and how to operate should be substantiated by the results of large, preferably randomised, prospective studies comparing surgical with non-surgical regimes in elderly patients suffering from an osteoporotic pelvic ring fracture.

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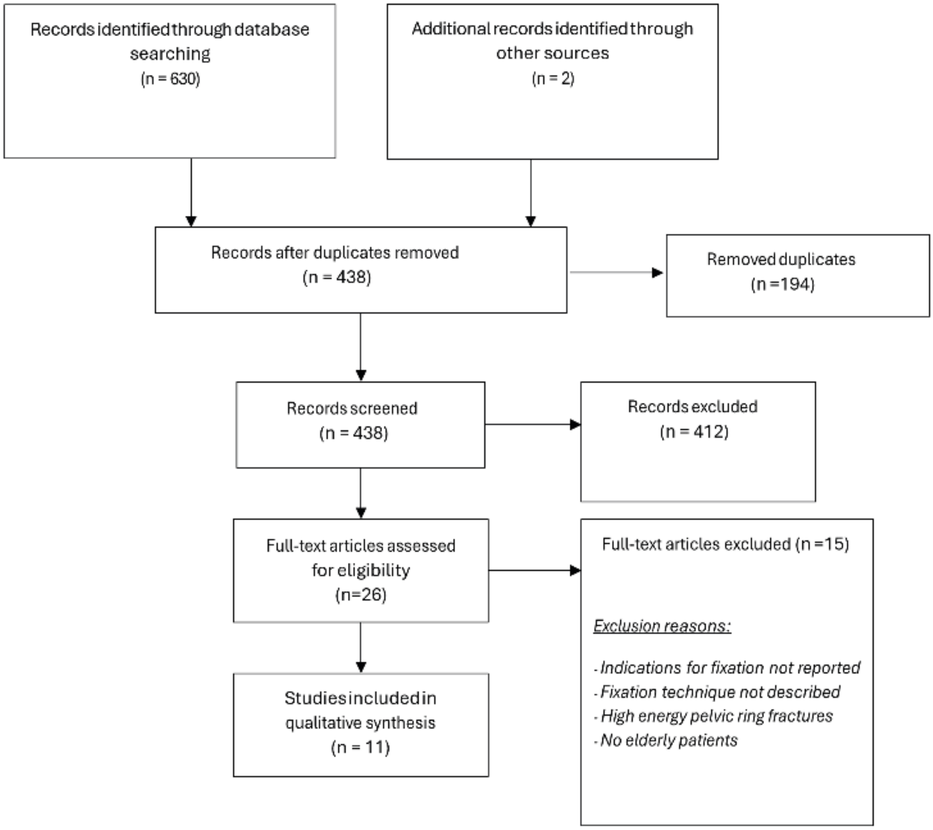
Tables and figures

Figure 1. PRISMA 2009 flow diagram showing the study selection process



4

Table 1. Comparative cohort studies: characteristics and outcomes

Study details	Study design	Patients, N	Mean Age (SD/ range)	Female %	Fracture type, N (%)	Indications for OM/ Time to surgery
Hotta 2021, Japan[19]	RC FFP I-II vs FFPIII- IV	84 OM: 8 *- FFP I/II: 6* *- FFPIII/IV:2* NOM: 76 *- FFP I/II: 47* *- FFPIII/IV:29*	83.5 (7.8)	92%	FFP I: 18 FFP II: 35 FFP III: 8 FFP IV:23	Failure of NOM: Not able to stand after 10 days. Surgery after: Mean 11.6 days
Osterhoff 2019, Germany[20]	RC Group 1 vs Group 2*	230 Group 1: OM: 60/148 NOM: 88/148 Group 2: NOM: 82	81 (60- 98)	NOM-OM: 81% NOM: 89%	**NR**	Failure of NOM: inability to mobilize after 3-5 days Anterior fixation: if displaced >1 shaft width + pain
Walker 2018, Canada[21]	RC OM vs NOM	41 OM: 16 NOM: 25	OM: 78.1 NOM: 77.7	OM: 87.5% NOM: 88%	OM: LC-1: 8 Sacral U: 8 NOM: LC-1: 18 Sacral U: 7	Failure of NOM: unable to ambulate or severe posterior pelvic pain with ambulation

* Group 1: initial NOM followed by OM if NOM failed; Group 2: only NOM
RC: retrospective cohort; SD: Standard deviation; FFP: fragility fracture of the pelvis; OM: operative management; NOM: non-operative management; A/P: anterior posterior.
NR: not reported; RS = Ramus screws; INFIX = anterior subcutaneous internal fixation; TISS = Trans ilio sacral screws

Anterior type of fixation N	Posterior Type of fixation	Mean follow up (SD/range)	Outcomes			
			Pain	*Mobility*	*Complications*	*Mortality*
None	TISS	408.7 days (254)	**NR**	Change in Graham scale: FFP I-II 0.25 FFP III-IV 0.23 *p=0.889*	Surgical: none	**NR**
Plate: 8 RS: 5 INFIX: 4	TISS	Group 1: 69 months (60-85) Group 2: 44 months (41-53)	**NR**	Majeed score - Group 1: 66.1 (SD 12.6) - Group 2: 65.7 (SD 12.5) *p=0.910*	In hospital -Group 1 34.5% - Group 2 17.1% *p=0.008*	1-year: - Group 1: 34 (23%) - Group 2: 14 (17%) *p=0.29*
None	TISS	**NR**	↓VAS (pre vs. post): - OM: 3.9 - NOM:0.6 *p<0.01*	Ambulatory at discharge: - OM: 100% - NOM:72 % *p <0.03*	None	None

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Table 2 Cohort studies with isolated posterior fixation: characteristics and outcomes

Study details	Study design	Patients N	Mean Age (SD/range)	Female %	Fracture type N, (%)	Indications for OM/ Time to surgery
Schmerwitz 2020 Germany[22]	RC	53	79.1 (7.8)	90%	FPP II: 13 FFP III: 22 FFP IV 18	Unstable fractures (FFP II/III/IV) + persistent pain. Surgery after: 55.5 days (3-720)
Obid 2020 Germany[23]	PC	13	83.9 (6.3)	100%	FFP II: 10 FFP III: 1 FFP IV: 2	Failure of NOM Surgery after: 2 weeks
Noser 2018 Switzerland[24]	RC	60	79.0 (9.0)	88%	FFP II: 17 FFP III: 26 FFP IV: 17	Failure of NOM Surgery after: 5 days

Posterior Type of fixation	Mean follow up (SD/range)	Outcomes			
		Pain	*Mobility*	*Complications*	*Mortality*
Plate	31.5 months (6-90)	Post hospital VAS: 2.4	IOWA Pelvic Score 85.6 (55-99)	- Surgical: 7 (13%) - Post-op: 9 (17%)	1 pt. died after 24 days post-op of pneumonia
Minimally invasive lumbo-pelvic fixation	4 weeks	NRS pre-op 7.18 (0.98) post-op 2.45 (0.93) P<0.001	TMT pre-op 4.15 (SD 3.67) TMT post-op 16.39 (SD 4.61) P<0.001	Surgical: 2 (15.4%) wound problem 1 rod dislocation 1 pneumonia 2	**NR**
TISS 8.3% open reduction	62 months (22) 46 lost to follow-up	**NR**	Majeed score N=14 available final FU: mean 65 points (SD 11) - FFP II: 67 - FFP III: 69 - FFP IV: 60 *(p=0.21)* 25% of all patients could return home FFP II: 6 (35%) FFP III: 5 (19%) FFP IV: 4 (24%)	Total: 26 (43.3%) - re-operation:2. (3.3%) - HA infections: 19 (31.7%) - TE 1 (1.7%) - Delirium: 7 (11.7 %)	In-hospital: 2 (3.3%) 1-year: 17 (28.3%)

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Table 3 Cohort studies with combined anterior and posterior fixation: characteristics and outcomes

Study details	Study design	Patients N	Mean Age (SD/range)	Female %	Fracture type N, (%)	Indications for OM/ Time to surgery
Ferry 2020, USA[25]	RC	50 FFP: 32	FFP: 78.0 (9.1)	FFP: 65.6 %	FFP: Zone 1: 3.8% Zone 2: 9.4% Zone3: 6.3% U-type:31.3% LC-II: 9.4%	Failure of NOM Surgery after: 5.6 days (SD 9.4)
Wong 2019, Hong Kong[26]	RC	17	80.1 (8.2)	94%	AO B1: 2 B2: 10 B3: 2 A/P column: 2 No class: 1	Failure of NOM Surgery after: 8.6 days (SD 2.4)
Eckardt 2017 Switzerland[27]	RC	50	79.1 (8.4)	86%	FFP II: 15 FFPIII: 10 FFP IV: 25	Failure of NOM
Schmitz 2015 Germany[28]	RC	15	79.9 (9.0)	93%	FFP II: 5 FFP III: 1 FFP IV: 9	Failure of NOM Surgery after: 32 days (SD 27)
Studer 2013 Switzerland[29]	RC	132 OM: 5	84 (66-100)	86 %	Pubic rami fractures	Failure of NOM Surgery after: 4-6 weeks

RC: retrospective cohort; SD: Standard deviation; FFP: fragility fracture of the pelvis; OM: operative management; NOM: non-operative management; A/P: anterior posterior; UTI: urinary tract infection; I-O: intra-operative; GI: Gastro-intestinal; EF: External fixator; TISS: trans ilio sacral screws; caTIFI: cement augmented trans-iliac internal fixator; caIF: cement augmented internal fixator; NR: not reported; N/A: not

Anterior type of fixation N	Posterior Type of fixation	Mean follow up (SD/ range)	Outcomes			
			Pain	*Mobility*	*Complications*	*Mortality*
If surgically needed. not further specified	TISS	FFP: 18.0 weeks (19)	**NR**	Ambulant post-discharge: 94% Time to ambulatory: 18.0 weeks	**NR**	1-year: 4 (12.5%)
Anterior column screw: 17	TISS: 12	18.7 months (2.8)	Post-op ↓VAS mean 3.3 P<0.001	5 pt. walked unaided 7 pt. required walking aids	Infected pin: 1 UTI: 3 acute delirium: 2 GI bleeding: 1 non-union: 1	None
Plate: 9 EF: 5	TISS	805 days (453)	VAS = 0, n=20.	**NR**	I-O bleeding: 1 Malpositioning screw:1 Screw loosening + re-op: 9 (18%)	1-year: 5 (10%)
EF: 5 Supra acetabular screw: 3	caTIFI: 4 TIFI: 4 caIF: 7	**NR**	**NR**	**NR**	Re-operations: 0 Screws hit iliosacral joint: 4 Screw perforated Ilium cortex: 1 Cement leakage: 0	**NR**
Plate: 2	TISS	1 year 2 (1.5%) Lost FU	**NR**	**NR**	**NR**	1-year: 24 (18.5%)

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Table 4 Indications for operative management (OM) and definition of non-operative management (NOM)

Study details	Indication for OM	Definition of NOM	Definition failure of NOM	Predefined period of NOM
Hotta 2021, Japan[19]	Failure of NOM	Full weightbearing exercises within pain limits. 40 min. of physio-therapy a day + adequate analgesics	Difficulty of standing: difficulty with auxiliary standing on 1 leg and /or 2 legs due to permanent pain	10 days
Osterhoff 2019, Germany[20]	Failure of NOM	Physiotherapy guided full weightbearing + adequate analgesics	Patient was not able to ambulate with a walker or crutches	3-5 days
Walker 2018, Canada[21]	Failure of NOM	Physiotherapy guided full weightbearing + adequate analgesics	unable to ambulate or severe posterior pelvic pain with ambulation	*NR*
Schmerwitz 2020 Germany[22]	Unstable fractures (FFP III/IV) or FFP II after failure NOM	Physiotherapy guided full weightbearing + adequate analgesics	Patient was not able to ambulate	*NR*
Obid 2020 Germany[23]	Failure of NOM	Physiotherapy guided full weightbearing + adequate analgesics	Patient were bedridden due to pain and were ambulatory before fractures	2 weeks
Noser 2018 Switzerland[24]	Failure NOM No contra-indications against general anesthesia	Physiotherapy guided full weightbearing + adequate analgesics	Not able to mobilize on walking aids	5 days
Ferry 2020, USA[25]	Failure of NOM	*not further specified*	Patient was not able to ambulate	3-5 days
Wong 2019, Hong Kong[26]	Failure of NOM	Physical therapy guided full weightbearing using adequate analgesics	Impaired mobilization due to persistent pain	*NR*
Eckhard 2017 Switzerland[27]	Failure of NOM	*not further specified*	Persistent pain limiting mobilization	*NR*
Schmitz 2015 Germany[28]	Displaced fractures or Failure NOM	Physical therapy guided full weightbearing using adequate analgesics	Not able to mobilize out of bed	*NR*
Studer 2013 Switzerland[29]	Failure of NOM	*not further specified*	Persistent pain limiting mobilization	4 -6 weeks

Supplementary materials

Supplemental Appendix I. Literature search term

Pubmed

("Pelvic Bones"[Mesh:NoExp] OR "Pubic Bone"[Mesh] OR pelvic*[tiab] OR sacrum*[tiab] OR sacral*[tiab] OR (ramus*[ti] AND superior*[ti]) OR (ramus*[ti] AND inferior*[ti]) OR ramus-superior*[tiab] OR ramus-inferior*[tiab] OR superior-ramus*[tiab] OR inferior-ramus*[tiab] OR superior-pubic-ramus*[tiab] OR inferior-pubic-ramus*[tiab]) AND ("Fractures, Bone"[Mesh] OR fractur*[tiab] OR injur*[tiab] OR trauma*[tiab] OR (broken*[tiab] AND ("bone"[tiab] OR bone'[tiab] OR bone's*[tiab] OR bones*[tiab]))) AND ("Fracture Fixation"[Mesh] OR surge*[tiab] OR surgi*[tiab] OR operate*[tiab] OR operati*[tiab] OR presurg*[tiab] OR perisurg*[tiab] OR postsurg*[tiab] OR preoperat*[tiab] OR perioperat*[tiab] OR postoperat*[tiab] OR repair*[tiab] OR reconstr*[tiab] OR re-constr*[tiab] OR incisi*[tiab] OR anesthe*[tiab] OR anaesthe*[tiab] OR fixat*[tiab] OR retrograde-transpubic-screw*[tiab] OR pubic-bridging-plate-osteosynthes*[tiab] OR (pubic[ti] AND bridg*[ti] AND plate*[ti] AND osteosynthes*[ti])) AND ("Aged"[Mesh] OR "Geriatric Assessment"[Mesh] OR "geriatrics"[MeSH] OR "Nursing Homes"[Mesh] OR "Homes for the Aged"[Mesh] OR adl[tiab] OR aged*[ti] OR aged-adult*[tiab] OR aged-individual*[tiab] OR aged-men*[tiab] OR aged-patient*[tiab] OR aged-people*[tiab] OR aged-person*[tiab] OR aged-population*[tiab] OR aged-women*[tiab] OR ageing*[tiab] OR aging*[tiab] OR centenarian*[tiab] OR community-dwelling*[tiab] OR comorbidities[tiab] OR elder*[tiab] OR falls[tiab] OR frail*[tiab] OR gds[ti] OR geriatr*[tiab] OR geront*[tiab] OR nonagenarian*[tiab] OR nona-genarian*[tiab] OR non-agenarian*[tiab] OR octagenarian*[tiab] OR octa-genarian*[tiab] OR octogenarian*[tiab] OR octo-genarian*[tiab] OR old-adult*[tiab] OR old-age*[tiab] OR old-individual*[tiab] OR old-men[tiab] OR old-patient*[tiab] OR old-people*[tiab] OR old-person*[tiab] OR old-population*[tiab] OR old-women*[tiab] OR older[ti] OR older-adult*[tiab] OR older-individual*[tiab] OR older-men*[tiab] OR older-old[tiab] OR older-olds*[tiab] OR older-patient*[tiab] OR older-people*[tiab] OR older-person*[tiab] OR older-population*[tiab] OR older-women*[tiab] OR oldest-adult*[tiab] OR oldest-individual*[tiab] OR oldest-men*[tiab] OR oldest-old*[tiab] OR oldest-patient*[tiab] OR oldest-people*[tiab] OR oldest-person*[tiab] OR oldest-population*[tiab] OR oldest-women*[tiab] OR senescen*[tiab] OR senior[tiab] OR seniors[tiab] OR septuagenarian*[tiab] OR psychogeriatrics[tiab]) AND ((fragil*[tiab] OR frail*[tiab] OR "Frail Elderly"[Mesh] OR insufficienc*[tiab] OR fatigue*[tiab]) OR (low-energ*[tiab] OR lowenerg*[tiab] OR (low*[ti] AND energ*[ti])))

Embase

(pelvic girdle/ OR exp pubic bone/ OR pelvic*.ti,ab,kw. OR sacrum*.ti,ab,kw. OR sacral*.ti,ab,kw. OR (ramus*.ti,ab,kw. ADJ3 superior*.ti,ab,kw.) OR (ramus*.ti. AND superior*.ti.) OR (ramus*.ti,ab,kw. ADJ3 inferior*.ti,ab,kw.) OR (ramus*.ti. AND inferior*.ti.) OR ramus-superior*.ti,ab,kw. OR ramus-inferior*.ti,ab,kw. OR superior-ramus*.ti,ab,kw. OR inferior-ramus*.ti,ab,kw. OR superior-pubic-ramus*.ti,ab,kw. OR inferior-pubic-ramus*.ti,ab,kw.) AND (exp fracture/ OR fractur*.ti,ab,kw. OR injur*.ti,ab,kw. OR trauma*.ti,ab,kw. OR (broken*.ti,ab,kw. AND ("bone".ti,ab,kw. OR bone'.ti,ab,kw. OR bones*.ti,ab,kw.))) AND (exp fracture fixation/ OR surge*.ti,ab,kw. OR surgi*.ti,ab,kw. OR operate*.ti,ab,kw. OR operati*.ti,ab,kw. OR presurg*.ti,ab,kw. OR perisurg*.ti,ab,kw. OR postsurg*.ti,ab,kw. OR preoperat*.ti,ab,kw. OR perioperat*.ti,ab,kw. OR postoperat*.ti,ab,kw. OR repair*.ti,ab,kw. OR reconstr*.ti,ab,kw. OR re-constr*.ti,ab,kw. OR incisi*.ti,ab,kw. OR anesthe*.ti,ab,kw. OR anaesthe*.ti,ab,kw. OR fixat*.ti,ab,kw. OR retrograde-transpubic-screw*.ti,ab,kw. OR pubic-bridging-plate-osteosynthes*.ti,ab,kw. OR (pubic.ti,ab,kw. ADJ3 bridg*.ti,ab,kw. ADJ3 plate*.ti,ab,kw. ADJ3 osteosynthes*.ti,ab,kw.) OR (pubic.ti. AND bridg*.ti. AND plate*.ti. AND osteosynthes*.ti.)) AND (exp aged/ OR exp geriatric assessment/ OR exp geriatrics/ OR exp nursing home/ OR exp home for the aged/ OR adl.ti,ab,kw. OR aged*.ti. OR aged-adult*.ti,ab,kw. OR aged-individual*.ti,ab,kw. OR aged-men*.ti,ab,kw. OR aged-patient*.ti,ab,kw. OR aged-people*.ti,ab,kw. OR aged-person*.ti,ab,kw. OR aged-population*.ti,ab,kw. OR aged-women*.ti,ab,kw. OR ageing*.ti,ab,kw. OR aging*.ti,ab,kw. OR centenarian*.ti,ab,kw. OR community-dwelling*.ti,ab,kw. OR comorbidities.ti,ab,kw. OR elder*.ti,ab,kw. OR falls.ti,ab,kw. OR frail*.ti,ab,kw. OR gds.ti. OR geriatr*.ti,ab,kw. OR geront*.ti,ab,kw.

OR nonagenarian*.ti,ab,kw. OR nona-genarian*.ti,ab,kw. OR non-agenarian*.ti,ab,kw. OR octagenarian*.ti,ab,kw. OR octa-genarian*.ti,ab,kw. OR octogenarian*.ti,ab,kw. OR octo-genarian*.ti,ab,kw. OR old-adult*.ti,ab,kw. OR old-age*.ti,ab,kw. OR old-individual*.ti,ab,kw. OR old-men.ti,ab,kw. OR old-patient*.ti,ab,kw. OR old-people*.ti,ab,kw. OR old-person*.ti,ab,kw. OR old-population*.ti,ab,kw. OR old-women*.ti,ab,kw. OR older.ti. OR older-adult*.ti,ab,kw. OR older-individual*.ti,ab,kw. OR older-men*.ti,ab,kw. OR older-old.ti,ab,kw. OR older-olds*.ti,ab,kw. OR older-patient*.ti,ab,kw. OR older-people*.ti,ab,kw. OR older-person*.ti,ab,kw. OR older-population*.ti,ab,kw. OR older-women*.ti,ab,kw. OR oldest-adult*.ti,ab,kw. OR oldest-individual*.ti,ab,kw. OR oldest-men*.ti,ab,kw. OR oldest-old*.ti,ab,kw. OR oldest-patient*.ti,ab,kw. OR oldest-people*.ti,ab,kw. OR oldest-person*.ti,ab,kw. OR oldest-population*.ti,ab,kw. OR oldest-women*.ti,ab,kw. OR senescen*.ti,ab,kw. OR senior.ti,ab,kw. OR seniors.ti,ab,kw. OR septuagenarian*.ti,ab,kw. OR psychogeriatrics.ti,ab,kw.) AND ((fragil*.ti,ab,kw. OR frail*.ti,ab,kw. OR exp frail elderly/ OR insufficienc*.ti,ab,kw. OR fatigue*.ti,ab,kw.) OR (low-energ*.ti,ab,kw. OR lowenerg*.ti,ab,kw. OR (low*.ti,ab,kw. ADJ3 energ*.ti,ab,kw.) OR (low*.ti. AND energ*.ti.)))

Results 8th of January 2022: 438 articles after removal of duplicates

5

Clinical implications of additional posterior fractures in combined anterior–posterior pelvic ring fractures in elderly patients

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P. van der Zwaal
I. B. Schipper
S. A. G. Meylaerts

Injury, 2023

Abstract

Objectives

Historically, pelvic ring fractures have been considered to occur predominantly in the anterior ring and therefore mechanically stable. Combined anterior and posterior (A + P) pelvic ring fractures are expected to be less mechanically stable and therefore to be associated with higher levels of pain and reduced mobility compared to isolated anterior fractures. The current study investigates the clinical relevance of combined A + P pelvic ring fractures in elderly patients.

Methods

A prospective multicentre cohort study was conducted in patients aged >70 years with anterior pelvic ring fractures after low-energy trauma diagnosed on conventional radiographs. All patients underwent an additional CT scan. Patients were divided into two groups: isolated anterior or combined A + P fractures. Patients were treated conservatively with adequate analgesia for at least one week. If patients could not be mobilised after conservative treatment, surgical fixation was performed. Numerical Rating Scale (NRS) pain scores, dependence on walking aids, and Activities of Daily Living scores (ADL) were measured at 2–4 weeks, and 3, 6, and 12 months after fracture.

Results

102 patients (age 81.1 ± 7.6 years) were included. Isolated anterior fractures were diagnosed in 25 (24.5%) and A + P fractures in 77 (75.5%) patients. Baseline characteristics did not differ between the two groups. Most patients were successfully treated conservatively, and 5 (4.9%) underwent percutaneous trans-iliac, trans-sacral screw fixation after failure of conservative treatment. At 2-4 weeks post-trauma, patients with A + P fractures had similar median pain scores (3 [range 0–8] vs. 5 [0–10], $p = 0.19$) and ADL scores (85 [25–100] vs. 78.6 [5–100], $p = 0.67$) but were more dependent on walking aids (92.8% vs. 72.2%; $p = 0.02$) compared to patients with isolated anterior fractures. There were no significant differences at 3 months. At one year follow-up the median NRS pain and ADL scores for both fracture groups were 0 and 100, respectively. Mortality was 10.8%, and additional loss to follow-up was 17.6%.

Conclusions

The vast majority of elderly patients with PRF have combined A + P fractures. The clinical implications of additional posterior pelvic ring fractures in elderly patients appears to be limited.

Introduction

Because of the increasing general life expectancy, osteoporotic fractures of the pelvis are becoming a clinically significant health problem [1, 2]. The associated loss of autonomy, institutionalization, morbidity, and healthcare costs appear to be comparable to those of patients with hip fractures [3,4]. Fragility fractures of the pelvis predominantly affect elderly women with osteoporosis and often occur after a low-energy fall or even occur spontaneously [3]. These types of fractures are rarely associated with haemodynamic instability or damage to important intrapelvic organs [4]. Not only the mechanism of trauma and patient characteristics, but also the fracture patterns observed in elderly patients, are different from those seen in young adults. Historically, pelvic ring fractures in elderly following low-energy trauma were thought to involve only the anterior pelvic ring, which was considered stable and generally treated conservatively [5]. However, several studies have reported additional involvement of the posterior pelvic ring, with percentages up to 60% on CT scan and 90% on MRI [6–8]. The aim of this prospective study was to identify additional posterior pelvic ring fractures using CT scan evaluation and to investigate the clinical impact of these additional fractures in terms of pain and mobility in elderly patients. It was hypothesised that combined anterior and posterior (A + P) pelvic ring fractures are associated with higher levels of pain and reduced mobility compared with isolated anterior ring fractures and may subsequently lead to a higher rate of complications (e.g. respiratory infections, decubitus ulcers, and thromboembolism) and increased mortality. If so, early detection of additional posterior pelvic ring fractures by routine CT scan evaluation would be important.

Methods

This prospective multicentre cohort study was conducted in two level 1 trauma centres in the Netherlands: the Leiden University Medical Center in Leiden and the Haaglanden Medical Center in The Hague. The study protocol was approved by the regional Medical Ethics Review Board.

Between 2018 and 2021, all elderly (> 70 years) patients presenting to the emergency departments (ED) of the participating centres with an anterior pelvic ring fracture (superior/inferior pubic ramus) diagnosed on plain pelvic radiographs after a low-energy trauma, were considered for inclusion. Patients were excluded if they (1) had associated injuries that would interfere with mobilisation using walking aids, (2) had insufficient knowledge of the Dutch language or another situation that interfered with answering questions about pain and mobility, (3) had a pathological fracture caused by bone malignancy or metastasis, (4) had received irradiation therapy of the pelvis or, (5) had undergone any form of early (< 1 week) surgical treatment for the acquired pelvic ring fracture. If a patient met the inclusion criteria and gave written informed consent, the pre-trauma pain score, Barthel Index of Activities of Daily Living score, use of walking aids, and current living situation were assessed with a short questionnaire in the ED of the participating hospitals. After inclusion, the patient work-up was according to the standard protocol, including pelvic X-rays series (AP, inlet/outlet radiographs). If an anterior fracture was diagnosed, a CT scan was performed to identify additional posterior fractures.

Fractures were classified according to the Rommens classification of Fragility Fractures of the Pelvis (FFP) [8]. All patients were treated conservatively for at least one week. The treatment consisted of a regimen of analgesics and physiotherapist-guided mobilisation. Analgesics included paracetamol and naproxen or diclofenac in combination with proton pump inhibitors (PPIs). If necessary, opioid agonists were prescribed, usually extended-release tablets (OxyContin®) of 5–10 mg in combination with immediate-release tablets (OxyNorm®) of 5 mg. If patients were unable to ambulate despite the analgesic within 7 days post-trauma, percutaneous screw fixation of the pelvic ring was considered.

Follow-up data were collected via telephone consultations using questionnaires: a Numerical Rating Scale (NRS) for pain, the Barthel Index of Activities of Daily Living (ADL; scoring range 0 [total dependence] to 100 [no dependence]), and questions about dependence on walking aids and living situation (living independently at home, living at home but dependent on home care or institutionalised in a nursing home) [9, 10]. These follow-up data were collected at 2–4 weeks and at 3, 6, and 12 months after the fracture.

Statistical analysis

Continuous baseline characteristics and outcome measures were compared between patients with an isolated anterior fracture and patients with combined A + P fractures, using the Student's *t*-test for normally distributed data or the Mann-Whitney test for skewed data. Categorical characteristics and outcome measures were compared using the Chi-squared test or, in case of expected cell counts <5, with the Fisher's Exact test. All outcome measures were univariably compared between the groups at each time point. Although initially planned, the repeated outcome measures were not analysed using multivariate mixed models, because the linearity assumption for linear regression analysis was not met due to the extremely skewed pain and ADL scores, even after transformation, and because the baseline characteristics of the study groups were very similar.

Results

Baseline

The overall mean age was 81.1 ± 7.6 years, and 85.3% were female. Ninety-four (92.2%) patients had fallen from a standing position, and eight patients had a low-energy road traffic accident. The median baseline ADL score was 100 (range 10–100), indicating no dependence. Of the total study population, 25 patients (24.5%) were dependent on walking aids indoors and outdoors prior to trauma. Twenty-five (24.5%) patients had an isolated anterior pelvic fracture (FFP Ia: 22; FFP Ib: 3), and 77 (75.5%) patients suffered from combined anterior and posterior (A + P) fractures of the pelvic ring (FFP IIa: 1; FFP IIb: 52; FFP IIc: 23; FFP IVc: 1). Baseline characteristics did not differ between the two fracture groups (**Table 1**).

Follow-up

The median NRS pain score at 2–4 weeks was 3 [range 0–8] for patients with an isolated anterior fracture compared with [0–10] for patients with combined A + P fractures ($p = 0.19$). No differences in NRS pain scores, and ADL scores were found between the groups during the remainder of the follow-up period (**Table 2**). At 2–4 weeks, patients with A + P fractures were significantly more dependent on walking aids indoors compared with patients with isolated pelvic ring fractures (92.8% vs. 72.2%; $p = 0.03$; **Table 2**). A total of five patients with FFP IIb: 3 or FFP IIc: 2 fracture types (4.9% of the study population) underwent surgical fixation during the follow-up period (**Table 2**). Minimally invasive fixation of the posterior fracture was performed using trans-iliac trans-sacral screw (TITS) fixation in all five cases, after a mean period of 13.6 ± 15.4 days. No major complications (including pneumonia, decubitus ulcers, wound infection) occurred during the conservative treatment period, or after surgery. Additional anterior fixation was not performed, as it was assumed that sufficient stability was achieved with posterior fixation alone, given that the anterior fractures were not displaced. No surgical complications were reported. A total of 11 patients (10.7%) died during follow-up. A further 18 patients (17.6%) were lost to follow-up due to progression of cognitive impairment, which made them unable to complete the questionnaire during follow-up (**Table 2**).

Discussion

The current study, including 102 mainly conservatively treated patients shows that geriatric patients with or without an additional posterior pelvic ring fracture have similar results regarding pain levels, mobility, and ADL. At 6 months, both fracture groups showed complete recovery to pre-injury levels regarding pain levels, and ADL (**Table 2**). Based on these results, the clinical relevance of additional posterior pelvic ring fractures seems limited.

According to hospital protocols, all included patients underwent a period of conservative treatment of at least 1 week, including physiotherapist-supervised weight-bearing and adequate analgesia. Only five patients required surgical intervention due to persistent immobilising pain. Historically, low-energy pelvic ring fractures in elderly patients have been treated conservatively, with analgesics and early full weight-bearing as soon as tolerated [11, 12]. Since the development of minimally invasive surgical techniques and improved peri-operative imaging, an increasing number of studies have been published advocating early fixation [13, 14].

The duration of the conservative treatment period in the participating hospitals (mean 13.6 ± 15.4 days) was longer when compared with the current literature [15,16]. Nevertheless, the majority of the patients recovered to pre-injury pain and mobility levels, and no immobility-related complications (e.g. pneumonia, urinary tract infections, decubitus ulcers) were observed. The overall mortality rate of 10.7% in this study is lower when compared with other conservatively treated cohorts and similar to cohorts in which early surgery is performed [17–19].

We recognize that the methods and results of the current study differ from the body of literature advocating early surgical fixation [20, 21]. However, it seems that the prolonged period of observation and mobilisation under analgesia does not increase the complication rate. We might even advocate a less aggressive treatment strategy for these injuries, despite the fact that surgical results in these patients are very promising [19, 22, 23].

The results of the current study suggest that the clinical relevance of additional posterior pelvic ring fractures is limited. Therefore, it seems unnecessary to routinely perform a CT scan in every geriatric patient with a pelvic ring fracture upon presentation to the emergency department. The results of the current study are consistent with our previously published review of the literature, which showed that patients' pain and mobility levels dictate the treatment regimen rather than the presence of additional posterior pelvic ring fractures [24]. However, if conservative treatment fails, a CT scan is recommended to assess for additional posterior injuries or signs of instability [19, 22].

Emerging evidence supports the use of Magnetic Resonance Imaging (MRI) or Dual Energy CT scans (DECT) for occult posterior pelvic ring fractures. These modalities have superior sensitivity for bone marrow abnormalities (including oedema and bone bruising) surrounding the fractures when compared with standard CT scans [18, 25, 26]. In patients with persistent pain, these bone bruises may be the only evidence for an occult fracture and a good reason for their complaints.

Limitations

NRS pain scores varied widely in both fracture groups at all time points (**Table 2**). Although the NRS is a widely accepted and valid measure of pain intensity, there are several external factors that potentially influence these scores (e.g. psychological factors and older patients; report more accurate pain scores when using a Visual Analogue Scale) [27, 28]. In the current study, we used the NRS instead of the Visual Analogue Scale (VAS) because the latter could not be conducted over the phone, but we did not correct the NRS for potential external factors that may have contributed to the large variation. Furthermore, a recent study reported additional posterior fractures in up to 90% of the patients when using MRI assessment [18, 29]. This may mean that the 75% of A + P fractures on the routine CT scan evaluation in this study is an underestimation.

This implies that there may have been patients in the isolated fracture group who actually had an additional occult posterior fracture that was missed on CT scan evaluation. Finally, the relatively short follow-up period of one year does not allow us to report on long-term outcomes, but our study showed full recovery to pre-injury levels for pain, mobility, and ADL after one year.

Conclusion

The current study shows that most geriatric patients with pelvic ring fractures have both an anterior and a posterior fracture. The clinical relevance of additional posterior pelvic ring fractures seems limited, since it is not associated with higher pain scores or reduced mobility compared with isolated anterior fractures. However, the exact extent of the injury becomes more relevant when conservative treatment fails.

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Tables and figures

Table 1. Patient characteristics

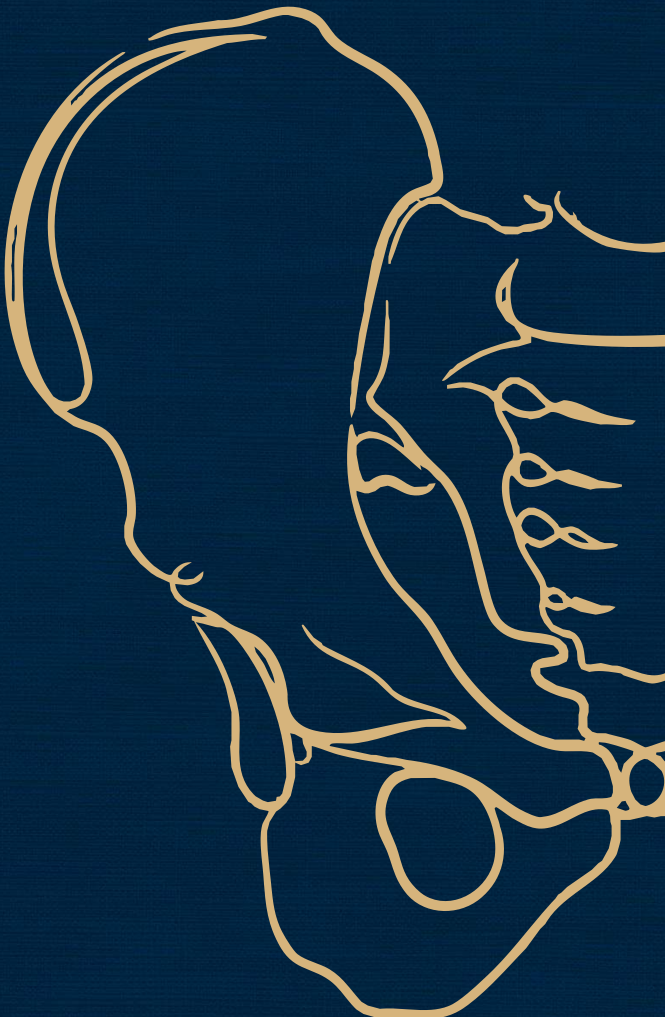
	All patients n = 102	Isolated anterior fracture n = 25	Combined fracture n = 77	P value
Age; mean (standard deviation)	81.3 (7.6)	82.7 (7.6)	80.9 (7.6)	0.29
Female; n (%)	87 (85.3)	23 (92.0)	64 (83.1)	0.35
Trauma mechanism; n (%)				1.00
Fall from standing	94 (92.2)	23 (92.0)	71 (92.2)	
Other	8 (7.8)	2 (8.0)	6 (7.8)	
Living situation before trauma				0.16
Independent (with or without help)	92 (93.9)	21 (87.5)	71 (95.9)	
Nursing home	6 (6.1)	3 (12.5)	3 (4.1)	
Barthel Index; median (range)	100 (10-100)	100 (50-100)	100 (10-100)	0.31
Dependence on walking aid; n (%)				1.00
No	61 (62.2)	15 (62.5)	46 (62.2)	
Only outdoors	12 (12.2)	3 (12.5)	9 (12.2)	
Indoors and outdoors	25 (25.5)	6 (25.0)	19 (25.7)	
Pain score at arrival in ER; median (range)	4 (0-10)	3 (0-9)	5 (0-10)	0.12
Pain score on leaving ER; median (range)	4 (0-9)	3 (0-9)	4 (0-9)	0.29

Table 2. Outcomes per follow-up moment and fracture type

	2-4 Weeks			3 Months		
	Isolated anterior n= 18	Combined n= 69	P	Isolated anterior n= 16	Combined n= 63	P
Pain (NRS); median (range)	3 (0-8)	5 (0-10)	0.19	0 (0-8)	1 (0-8)	0.27
Daily Activity Score (Barthel Index); median (range)	85 (25-100)	85 (5-100)	0.67	90 (35-100)	95 (5-100)	0.20
Dependent on walking aid indoors; n (%)	13 (72.2)	64 (92.8)	**0.03**	7 (43.8)	28 (44.4)	0.96
Dependent on walking aid outdoors; n (%)	17 (94.4)	67 (97.1)	0.51	7 (43.8)	40 (63.5)	0.15
Fixation performed; n (%)	0 (0)	4 (5.8)	0.58	0 (0)	1 (1.5)	1.0
Lost to follow-up; n (% of initial group)	7 (28.0)	8 (10.4)		9 (36.0)	14 (18.2)	
Mortality; n	0	4		0	9	
Due to cognitive impairment; n	7	4		9	5	

5

6 Months			1 Year		
Isolated anterior n= 16	Combined n= 61	P	Isolated anterior n=15	Combined n=58	P
0 (0-2)	0 (0-8)	0.06	0 (0-5)	0 (0-7)	0.39
100 (30-100)	100 (20-100)	0.56	100 (15-100)	100 (15-100)	0.90
4 (23.5)	23 (37.7)	0.28	5 (33.3)	20 (34.5)	0.93
8 (47.1)	31 (50.8)	0.78	7 (46.7)	32 (55.2)	0.56
0 (0)	0 (0)	-	0 (0)	0 (0)	-
9 (36.0)	16 (20.8)		10 (40.0)	19 (24.7)	
0	10		0	11	
9	6		10	8	

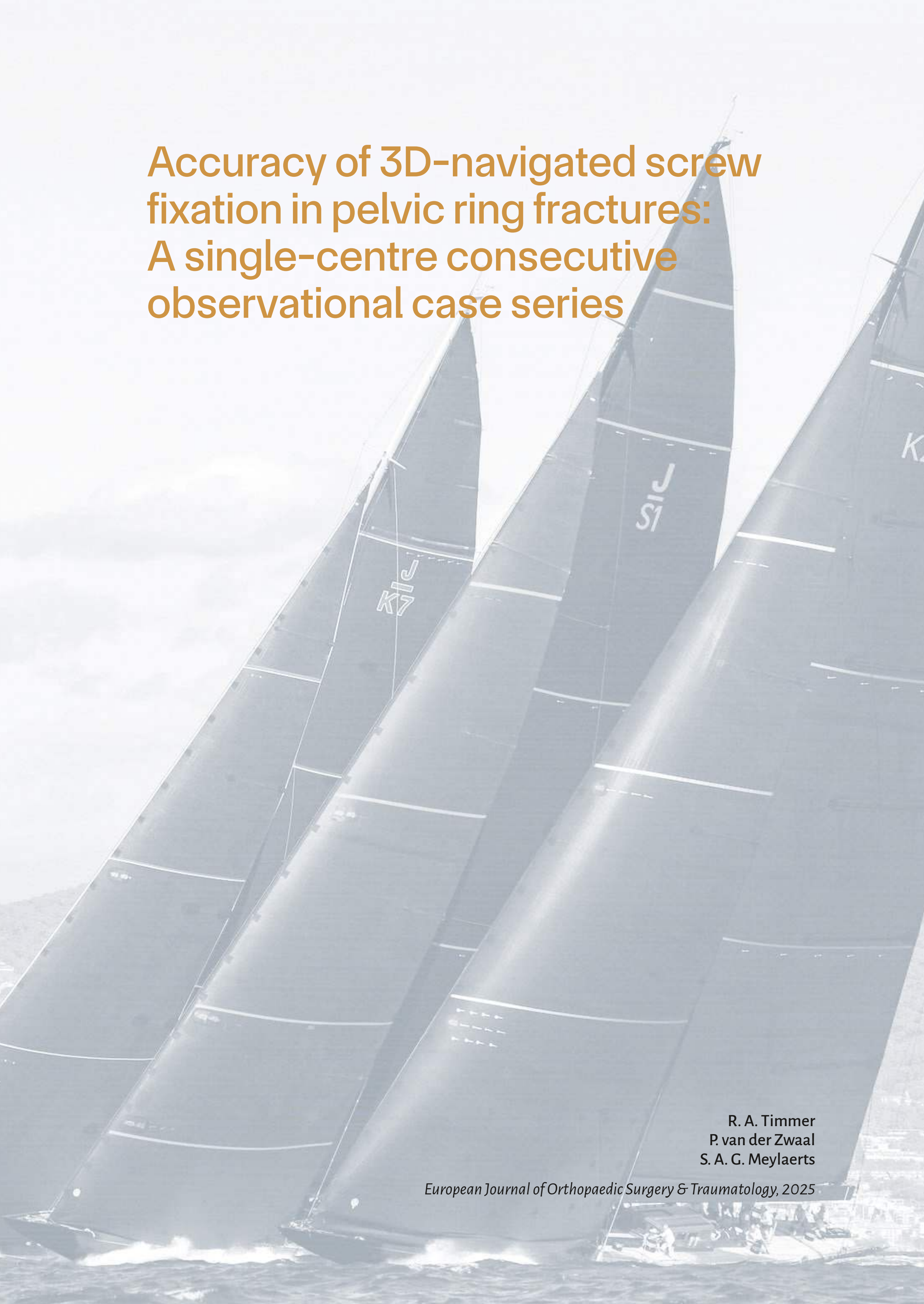


Part III

Minimal invasive screw fixation in pelvic ring fractures

6

Accuracy of 3D-navigated screw fixation in pelvic ring fractures: A single-centre consecutive observational case series



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Abstract

Introduction

Conventional 2D fluoroscopy-based screw fixation of pelvic ring fractures has high screw misplacement rates and can be technically challenging. Implementation of 3D image guidance is presumed to simplify screw placement and improve procedural safety. The objective of this study was to evaluate the accuracy of 3D navigation in percutaneous screw fixation of pelvic ring fractures.

Methods

A consecutive case series including all patients undergoing 3D-guided screw fixation of pelvic ring fractures between 2019–2022 was conducted. Primary study endpoints were screw misplacement, neurological complications, and surgical site infections. Data were analysed using descriptive statistics.

Results

A total of 90 consecutive patients (180 screws) were included, with 120 transiliac-transsacral- screws (TITS) and 60 sacral-iliac (SI) screws used for posterior fixation, five retrograde transpubic screws placed for anterior fixation, and 23 antegrade screws were placed into the superior pubic rami. For two patients (2.7%), screw misplacements were observed. No neurological complications occurred due to screw misplacement.

Conclusions

The results of the current study shows that 3D navigation provides excellent screw placement accuracy, with minimal screw misplacements, and no neurological complications due to screw misplacement.

Introduction

Over the last decade, the interest in and use of minimally invasive techniques in orthopaedic-trauma surgery have increased, as they are associated with less postoperative pain, shorter hospital stays, and fewer complications [1]. When it comes to percutaneous screw fixation of pelvic ring fractures, screw misplacement is frequently reported, with conventional 2D fluoroscopy resulting in misplacements rates of up to 20% [2, 3]. In particular, sacral iliac (SI) or transiliac-transsacral screw (TITS) fixation using 2D fluoroscopy is challenging due to complex three-dimensional morphology of the sacrum. The anatomy of the sacrum is characterized by narrow osseous corridors and the close proximity of neurovascular structures, with sacral dysmorphism being a frequent additional difficulty [4–6]. Additional factors, such as bowel gas, impaired visualization in obese patients, and decreased bone density in geriatric patients, can further reduce intraoperative visibility and increase the risk of iatrogenic neurovascular injury [7, 8].

Despite the high incidence of screw misplacement and its potentially devastating effects, conventional 2D fluoroscopy, as first described by Matta and Saucedo in 1989, remains the widely accepted standard technique [9, 10]. In recent years, the use of peri-operative 3D imaging and navigation has increased exponentially. In spine surgery, there is already a clear consensus on 3D-navigated pedicle screw placement, demonstrating a significant reduction in screw misplacement, operative time, and radiation dose [11, 12]. These advantages suggest that similar benefits could be achieved in pelvic fracture surgery.

3D-navigated screw placement is rapidly growing in popularity because of its potentially superior accuracy compared with 2D-navigated screw placement in pelvic ring fractures [13]. Therefore, the primary goal of this consecutive case series is to determine the accuracy of 3D-navigated screw placement in pelvic ring fractures and to evaluate potential complications, including neurovascular injury, surgical site infections, operative duration, and radiation exposure.

Methods

Patient selection and data collection

All consecutive patients with pelvic ring fractures who underwent 3D-navigated screw fixation at an urban level 1 trauma centre in the Netherlands between 2019 and 2022 were included in this observational case series. Patients who underwent open reduction and internal fixation were excluded.

Baseline characteristics (patient demographics, trauma mechanism, fracture classification) and clinical time points (admission, surgery, discharge) were systematically recorded for all included patients. For elderly patients (>70 years), fracture classification was determined using both the Young and Burgess classification and the classification proposed by Rommens et al. [14, 15].

For all patients, outcomes were analysed in four categories: technical, surgical, neurological, and material-related complications. Technical complications were defined as intraoperative K-wire and/or screw misplacement, i.e., perforation of the cortical bone (foraminal or anterior sacral cortex). Surgical complications included postoperative surgical site infections (SSIs), subdivided into superficial infections treated with antibiotics and deep infections requiring operative debridement. Neurological complications included loss of sensation, decreased motor function, and persistent neuropathic pain. For all patients experiencing neurological complications after surgery, a neurologist was consulted to differentiate between pre-existing, trauma-induced, or surgery-related deficits. Material-related complications included screw breakage, backing out of screws, and persistent pain attributed to the implants. Results regarding the radiation dose, effective dose (millisievert, mSv), and Dose Length Product (DLP, Gy·cm²) were obtained from the O-arm's built-in dosimeter.

Surgical procedure

All included patients were operated on using a standardized surgical setup. Patients were positioned supine on a radiolucent sacral bone foam positioning block and receiving general anaesthesia. Following sterile draping, the iliac crest was palpated, and a two-pin reference frame™ (Medtronic, USA) for the StealthStation™ S8S navigation system (Medtronic, USA) was percutaneously attached to the superior iliac crest (**Figure 1, Figure 2A**). Three-dimensional images were generated using the O-arm™ Imaging System (Medtronic, USA) linked to the StealthStation™ S8 navigation system (Medtronic, USA), which determined the patient's position and orientation via the reference frame™ (Medtronic, USA) (**Figure 2A**). To minimize radiation exposure to the operating team, staff temporarily exited the operating room while a scout scan was obtained using the O-arm™ Imaging System, following the same imaging protocol for all patients. The intraoperative scan from the O-arm™ Imaging System (Medtronic, USA) was displayed in three planes: coronal, sagittal, and transverse, with an additional three-dimensional reconstruction (**Figure 2B**). The navigated drill sleeve™ (Medtronic, USA) was calibrated and used to plan skin incisions, with the projected trajectories overlaid on the scout scan to mark the incision site (**Figure 2B**).

A 3-cm skin incision was made, and blunt dissection down to the outer cortex of the ilium was performed. The calibrated navigated drill sleeve was inserted, and the K-wire was positioned through the sleeve. The projected trajectory was continuously monitored in three dimensions using the StealthStation™, which provided real-time feedback on the previously obtained scout scan. After placement of the navigated K-wire, a control run was performed using the O-Arm™ to confirm correct positioning and rule out neuroforaminal perforation. If positioning was uncertain, the K-wire was removed and replaced, followed by another control scan. Once satisfactory placement within the correct bone corridor was confirmed, the screw trajectory was predrilled and a fully threaded 6.5-mm screw of the appropriate length, including a washer, was inserted over the K-wire. Additional fractures of the anterior pelvic ring requiring fixation were addressed using the same incision and same procedure, targeting the superior ramus. Correct screw positioning of both the anterior and posterior screws was verified on a final O-arm scan if necessary.

Ethics statement

The included patients represent a subset of a previously established database (Reference number 2020-125). The study was approved by the hospital's board, and the medical ethics committee waived the requirement for informed consent for participation due to the observational nature of the research. Informed consent was obtained from all individuals depicted for the use of photographs in this publication. All data were handled in accordance with institutional guidelines and the principles of the Declaration of Helsinki.

Statistical analysis

All data were analysed using IBM SPSS Statistics version 30. Continuous baseline characteristics and outcome measures were summarized using descriptive statistics (mean ± standard deviation or median with interquartile range, as appropriate). Categorical variables were presented as frequencies and percentages.

Results

Baseline

Of the 184 patients who underwent any form of pelvic fracture surgery in our centre, 90 patients received 3D-navigated screw fixation between 2019 and 2022 and were included in the study. In total, 180 posterior screws were placed: 120 transiliac-transsacral screws (TITS) and 60 sacroiliac (SI) screws. Twenty-eight pubic ramus screws were placed. Five of the anterior screws were placed retrograde, and the remaining 23 were placed antegrade. The median operation time was 40.0 (8–133) minutes. Patients receiving non-percutaneous surgery or open reduction and internal fixation were excluded from this study. The mean effective radiation dose of all procedures was 24.4 mSv with a corresponding DLP of 4.71 Gy·cm^2. The radiation exposure was primarily attributable to the intraoperative O-arm acquisitions, which typically consisted of two runs: an initial scout scan and a subsequent scan to confirm the position of the K-wires. In cases where K-wires required repositioning due to unsatisfactory placements, an additional scan was performed.

The majority (75%) of the patients were female with a mean age of 63.6 ± 22.4 years. Fall from standing (n=43; 47.8%) followed by falls from height (n=21; 23.3%) were the most common trauma mechanism (**Table 1**).

Patients were admitted to the hospital for a median period of 7.5 days (1–66). Prolonged hospital stays were primarily related to difficulties in arranging discharge to rehabilitation facilities or home, rather than to medical complications. Surgery was performed at a median of 2.0 days (0–14) after admission, and patients were discharged after a median of 5.0 days (1–63) (**Table 2**).

Post-operative outcomes

Screw misplacement occurred in 2 of 90 patients (2.7%). In both cases, the transiliac-transsacral (TITS) screw showed a minimal cortical breach of the anterior cortex of the ipsilateral sacral ala. Importantly, no neuroforaminal breach or iatrogenic injury to neurovascular structures was observed in any patient (**Table 2**). Three patients were diagnosed with surgical site infections (SSIs); all had sustained high-energy trauma. None of these fractures were open, nor had they undergone prior temporary external fixation. In two patients, superficial infections occurred at the insertion site of the posterior TITS screw and were successfully treated with oral antibiotics (flucloxacillin) for 7 days. In one patient suffering from a Morel-Lavallée lesion on the right thigh after high-energy trauma, a deep infection occurred at the insertion site of the posterior TITS screws. Multiple operative debridements were needed, and the patient was treated with intravenous antibiotics for an extensive period; however, no removal of internal fixation material was needed. Material-related complications required screw removal in 14 patients (16.7%). The majority of removals were due to pain related to the implants, followed by loosening of the SI screws in six patients and backing out of pubic ramus screws in two patients. In addition, one patient required removal of a pubic ramus screw due to breakage (**Table 2**).

Seven (7.8 %) patients reported neurological complications (**Table 2**). All these patients were referred to the neurologist for further examination. After careful evaluation by the neurologist, the neurological complaints were attributed to the traumatic injuries rather than to pre-existing conditions or the surgery/screw placement. Retrospectively, the patients also acknowledged that these complaints had been present after the accident and prior to surgery, which was confirmed by the documentation in the patient files.

Discussion

In this study, we investigated the safety of 3D-navigated screw fixation in 90 patients with pelvic ring fractures resulting from low- or high-energy trauma. A total of 180 posterior screws were placed, including 120 TITS screws and 60 SI screws, along with 28 pubic rami screws. Our study demonstrated a very low rate of screw misplacement of 2.7%, limited to minor perforation of the anterior cortex of the sacral ala on the ipsilateral side, without any neuroforaminal perforation or neurological injury. These results align with the literature reporting 0–10% misplacement using 3D navigation and represent a clear improvement compared with the reported incidence of 15–20% described with conventional 2D fluoroscopy [2, 16-19]. Similarly, recent studies by Gilli et al., Zwingmann et al., and Richter et al. reported slightly lower accuracy rates of 83%, 81% and 85%, respectively, for screw placement without cortical or neuroforaminal perforation, compared with 96.3% in our series [20-22]. We believe this superior accuracy of 3D-navigated screw fixation in pelvic ring fractures is largely attributable to the intraoperative real-time visualization of the osseous sacral corridors and the feedback on the projected screw trajectories provided to the surgeon. This is particularly valuable in complex cases, such as those involving sacral dysmorphism in S1 (present in 41% of the patients), and is supported by a recent review including 3D-navigated screw navigation in such anatomically challenging cases [18].

The mean effective radiation dose per patient in our study was 24.4 mSv originating from the intraoperative O-Arm™ runs with a Dose Length Product (DLP) of 4.71 Gy·cm². These values are in line with previously reported data on spine and pelvic screw fixation using 3D navigation [23-26]. The major limitation in comparing reported radiation doses across studies is the considerable variability, which is influenced by the patient characteristic (e.g. body-mass index), differences in scan protocol and in reporting of radiation units, making direct comparisons difficult. Importantly, the radiation exposure to the surgical teams was minimized by temporarily leaving the operating room during scanning, in accordance with the standard radiation safety protocols. This represents a key advantage over 2D fluoroscopy-based navigation where spot or continuous imaging is required during K-wire and screw insertion, and the surgical team is directly exposed to the radiation. Consistent with previous reports, 3D navigation reduces radiation exposure to the surgical team, as they can leave the operating room during scanning [19, 27, 28]. For patients, however, whether overall radiation exposure is reduced remains controversial; doses appear higher with 3D navigation but remain within acceptable limits when compared with 2D fluoroscopy. The implementation of low-dose CT protocols into the 3D navigation workflows has the potential to substantially reduce patient exposure without compromising image quality. Ultra-low-dose pelvic CT with thin filtered scanning can achieve effective doses as low as 0.38mSV (approximately six times lower than standard pelvic CT scans), with overall dose reductions of 55-60% reported in recent studies [29, 30].

Surgical site infections (SSIs) occurred in three patients (3.3%), all following high-energy closed pelvic ring fractures. Two patients experienced superficial infections, which were successfully managed with oral antibiotics. One patient with a Morel-Lavallée lesion developed a deep infection at the posterior TITS screw site, requiring multiple operative debridements and prolonged intravenous antibiotic therapy. Importantly, no hardware removal was required because of SSIs. SSI rate in our cohort was low and similar to the reports in the literature. SSIs appear more related to the severity of trauma and associated soft-tissue injury rather than to the navigated procedure itself [31–33]. 3D-navigated screw placement using the O-arm™ does not increase the risk of postoperative infection compared to conventional techniques [16, 18]. Although the surgical team briefly leaves the operating room during scanning and thus exits the laminar flow zone above the sterile field, the influence on SSI appears negligible.

Although no hardware removal was required due to infection, hardware removal was necessary in 14 (16.7%) of the patients. These events were not related to the navigation technique or screw accuracy but rather to biomechanical factors, such as symptoms related to the osteosynthesis (n=5) or loss of screw purchase resulting in backing out of the SI screws (n=6). Seven patients (7.8%) reported neurological complaints; all were evaluated by a neurologist. For all patients, the complaints were attributed to the initial traumatic injuries rather than to the surgical procedure or screw placement. Notably, neither of the two patients with screw misplacement experienced neurological symptoms, and their hardware was retained. These findings highlight that patient-specific factors, such as fracture biomechanics, fracture pattern, and trauma mechanism, appear to be more relevant causes of postoperative complaints than the navigation technique.

While our results are encouraging, limitations must be acknowledged. The single-centre design and the modest sample size of 90 patients may affect the generalizability of the findings. Because 3D screw navigation in pelvic fractures is the standard of care in our institution, comparative data with 2D fluoroscopy were not available. Long-term outcomes, including functional aspects and quality of life, as well as cost-effectiveness, were not addressed, as our focus was on procedural safety and accuracy.

The efficacy and safety of this technique also depend on a dedicated, well-trained surgical team. We believe the high accuracy, relatively short operation time of 40 minutes, and the low SSI rate achieved in our series are the result of the expertise of our surgical team. Nonetheless, evidence indicates that 3D navigation is generally more accessible for novice orthopaedic surgeons and has a relatively short learning curve of 15–35 cases, with near-perfect accuracy achievable even in less-experienced hands [2, 34]. In contrast, estimates for 2D fluoroscopy-guided screw navigation suggest that 40-50 cases are required for consistent accuracy, with misplacement rates of up to 20% even among experienced surgeons [2, 35, 36]. Whether the safety profile of traditional 2D fluoroscopy navigation can match 3D-navigated screw placement in pelvic fractures remains uncertain. Acceptable misplacement rates with 2D fluoroscopy appear to be achievable primarily in high-volume pelvic trauma centres. Our hospital, one of ten level 1 trauma centres in the Netherlands and a tertiary referral centre for pelvic fractures, does not reach the annual pelvic ring fracture volumes seen in the major U.S. centres. This reflects a common situation in the Netherlands, where a dense population combined with a relatively high number of level 1 trauma centres results in less centralization and lower per-centre case volumes compared to the U.S. [18, 37]. Consequently, Dutch centres generally treat fewer pelvic fractures annually, whereas in the U.S., 2D fluoroscopy remains the standard of care [38-40].

Given our findings and current evidence, we advocate for the routine implementation of 3D navigation in percutaneous screw fixation of pelvic ring fractures, particularly in medium-volume centres such as those in the Netherlands. This technology not only improves the accuracy and safety of screw placement in pelvic ring fractures but also simplifies the procedure, enhances surgical training, and is particularly beneficial in anatomically complex cases, including those with sacral dysmorphism.

Conclusion

Our study demonstrates that 3D-navigated screw fixation for pelvic ring fractures is safe and effective, with low screw misplacement. Although occasional perforation of the anterior cortex may occur, these events did not result in neurological injury and are minor compared to the higher misplacement and neurovascular risk associated with conventional 2D fluoroscopic screw navigation. Based on these findings, we recommend adopting 3D navigation for percutaneous screw placement in pelvic ring fractures whenever available. This approach provides an accurate, reproducible, and safe method, particularly in anatomically complex regions of the sacrum.

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Tables and figures

Table 1. Patient characteristics

	All patients n = 90
Age; mean (standard deviation)	63.6 (22.4)
Female; n (%)	68 (75.6)
High energy trauma; n (%)	38 (42.2)
Trauma mechanism; n (%)	
Fall from standing	43 (47.8)
Fall from height	21 (23.3)
Traffic accident	15 (16.7)
Other	3 (3.3)
Unknown trauma mechanism	8 (8.9)
Fracture classification Youngs and Burgess; n (%)	
APC-2	1 (1.1)
APC-3	2 (2.2)
LC-1	46 (51.1)
LC-2	5 (5.6)
LC-3	21 (23.3)
VS	7 (7.8)
Combined	2 (2.2)
Isolated sacral fracture	6 (6.7)
Fracture classification Rommens; n (%)	
FFP IIa	3 (3.3)
FFP IIb	21 (23.3)
FFP IIIa	1 (1.1)
FFP IIIb	1 (1.1)
FFP IIIc	7 (7.8)
FFP IVb	6 (6.7)
FFP IVc	9 (10.0)

Table 2. Outcomes

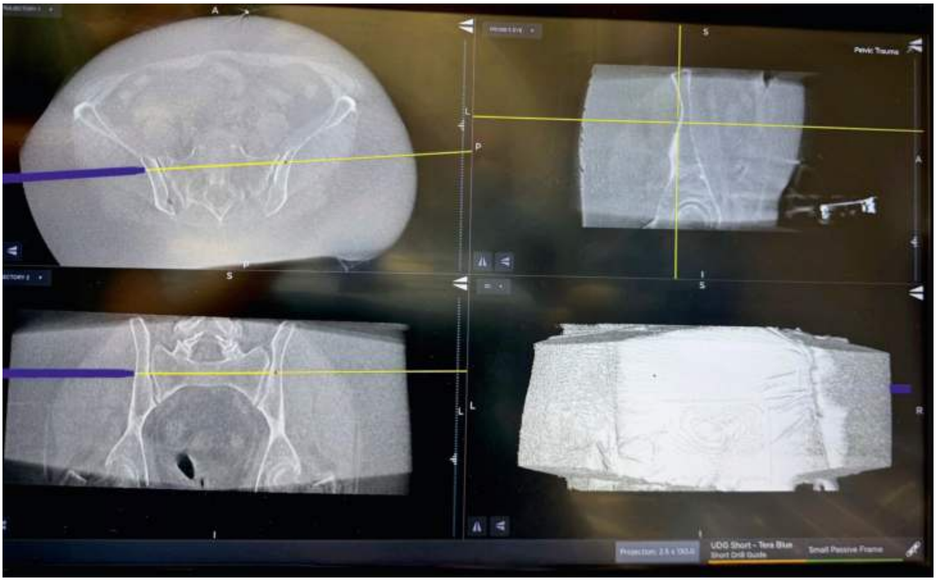
	All patients n = 90
Hospital admission in days; median (range)	7.5 (1-66)
Surgery after admission in days; median (range)	2.0 (0-14)
Discharge after surgery in days; median(range)	5.0 (1-63)
Delayed Surgery; n (%)	22 (24.4)
Delayed presentation	13
Initial conservative period at home	5
Referral from another clinic	4
Delayed surgery after days; median (range)	45.0 (6-338)
Technical complications; n (%)	2 (2.7)
Screw misplacement	2
Perforation of neuroforamina	0
Surgical complications n (%)	7 (7.8)
Superficial surgical site infection	2
Deep surgical site Infection	1
Non-union	4
Neurological complications; n (%)	7 (7.8)
Loss of sensation	1
Decreased motoric function	2
Persistent neuropathic pain	4
Material related complications; n (%)	14 (16.7)
Screw breakage of pubic ramus screw	1
Screw loosening SI screws	6
Screw loosening pubic ramus screws	2
Screw removal due to pain	5

Figure 1 and Figure 2. Standard surgical setup for posterior and anterior 3D-navigated pelvic screw fixation

Figure 1A. Positioning of the O-arm™ Imaging System (Medtronic, USA) prior to sterile draping

Figure 2A. Reference frame attached to two percutaneously inserted K-wires in the patient's iliac crest, shown in conjunction with the corresponding navigated drilling guide (Medtronic, USA)

Figure 2B. StealthStation™ S8 (Medtronic, USA) navigation interface illustrating the projected drilling trajectories superimposed on the intraoperative O-arm recon scan. The display demonstrates multiplanar imaging (clockwise from the lower left quadrant: coronal, transverse, and sagittal planes) in addition to a three-dimensional reconstruction (lower right quadrant)



7

Effect of hardware removal after percutaneous screw fixation of posterior pelvic ring fractures on pain and functional outcomes

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Submitted

Abstract

Introduction

Chronic postoperative pain following percutaneous screw fixation for unstable posterior pelvic ring fractures is frequently observed. This study aimed to assess the impact of hardware removal on pain levels, functional outcomes, and general health.

Methods

A single-centre retrospective cohort study was conducted, including all adult patients treated for posterior pelvic ring fractures using 3D-navigated percutaneous screw fixation between 2019 and 2024 at a level 1 trauma centre in the Netherlands.

Pain, function, and general health were evaluated using validated questionnaires before and after hardware removal. Pain was measured using the Numeric Rating Scale (NRS), function with the Majeed Pelvic Score (MPS), and general health with the EQ-5D. Logistic regression analysis was used to identify risk factors for hardware removal. Pain was measured with a Numeric Rating Scale (NRS), function with the Majeed Pelvic Score (MPS) and general health with the EQ-5D before and after removal. Logistic regression analysis was utilized to identify risk factors for hardware removal.

Results

Of 116 consecutive patients, 24 (20.7%) underwent hardware removal. The primary reasons for hardware removal were pain (51.9%) and screw loosening (37.0%). Post-removal, the mean NRS pain score significantly improved from 5.6 ± 2.8 to 3.8 ± 3.0 (p < 0.01). The MPS improved from 65.8 ± 20.1 to 79.4 ± 18.1 (p<0.01). Significant improvements were also observed in the EQ-5D score (0.48 ± 0.35 to 0.71 ± 0.29; p < 0.01).

Conclusion

Hardware removal after percutaneous screw fixation for a posterior pelvic fracture significantly reduces pain and improved functional outcomes, particularly in younger patients with persistent pain.

Introduction

Pelvic ring injuries can result in significant morbidity and mortality, often arising from high-energy trauma such as traffic accidents [1–4]. The aging population in the Netherlands and other developed countries has led to an increased incidence of osteoporotic pelvic ring fractures, mainly caused by low-energy trauma (LET) [3–6]. The indications for surgical fixation of osteoporotic pelvic ring injuries are poorly defined and mainly based on expert opinion. Minimally invasive treatment of anterior and posterior pelvic ring fractures, similar to the techniques used for high-energy fractures, is generally preferred, especially in frail elderly patients [7, 8].

Percutaneous sacroiliac (SI) or transiliac-transsacral (TITS) screw fixation has been established as a safe and effective technique. Advances in intra-operative image-guided (3D-CT-guided) navigation have significantly improved surgical accuracy and outcomes [9–12]. Despite these advancements, postoperative complications continue to occur, with variable frequencies reported in the literature. The most commonly observed complications include screw malposition (6–15.4%), nerve injury (2–3.2%), and chronic pain (3–48%) [10, 13–15].

While nerve injuries are generally attributed to screw perforation of the sacral neuroforamina, the underlying cause of chronic pain after fixation—aside from nerve injury—remains a topic of debate [14, 16, 17]. Rigid fixation across the sacroiliac (SI) joint and loosening of osteosynthesis material (OSM) have been hypothesized as contributing mechanisms [16, 17].

Several studies have suggested that hardware removal may alleviate these symptoms. Reported rates of hardware removal range from 5% to 25%, with pain relief achieved in 83–100% of cases [17–19]. Most studies have focused on younger patients (<65 years) and found that male patients are more likely than females to undergo removal [16–19]. Nevertheless, no consensus exists regarding the indications for hardware removal of percutaneous TITS or SI screws after pelvic ring fixation [20].

Therefore, this study aimed to evaluate the effect of hardware removal after percutaneous 3D-navigated screw fixation of pelvic ring fractures on pain, function, and quality of life, and to identify factors associated with the need for removal.

Methods

Study design and patient population

This single-centre retrospective cohort study was conducted at Haaglanden Medical Centre, a level 1 trauma centre and regional referral centre for pelvic fractures in The Hague, The Netherlands. All percutaneous pelvic ring fracture fixations in our centre are performed using intra-operative 3D navigation with the O-arm™ (Medtronic, Louisville, USA) and StealthStation™ S8 navigation system. All consecutive adult patients (≥18 years) who underwent 3D-navigated percutaneous screw fixation for a posterior pelvic ring fracture between January 2019 and April 2024 were considered for inclusion. Patients with pathological fractures secondary to bone malignancy were excluded.

Outcomes and other study parameters

Data were collected from electronic patient records, including baseline characteristics such as demographics, trauma mechanisms, and fracture classification according to the Young and Burgess classification [21]. Surgical details, screw placement characteristics, and postoperative outcomes were also recorded.

For patients who underwent hardware removal, the indication, timing, and radiological findings were additionally documented. Complications after primary and removal surgery were registered, including wound infection, nerve injury, screw loosening or malposition, mal- or non-union, chronic pain, and overall mortality. Indications for screw removal were documented for all hardware removal procedures.

Screw loosening was defined as radiolucency around the screws, screw migration or loss of fixation on follow-up imaging. Chronic pain, defined as pain lasting longer than 12 weeks, as well as nerve irritation, were recorded only when verified by a neurologist or pain specialist. Concomitant injuries that could interfere with pelvic function or pain scores, such as lower spine or hip fractures, were also recorded.

The primary outcomes of interest were pain and function after hardware removal. For patients who underwent hardware removal, outcome data were collected through structured telephone interviews after a minimum follow-up of 3–4 months following the procedure. Pain was measured using the Numerical Rating Scale (NRS), and pelvic function was assessed with the Majeed Pelvic Score (MPS), which evaluates five domains: pain (0–30 points), work (0–20 points), sitting (0–10 points), sexual intercourse (0–4 points), and standing (0–36 points). The total score ranges from 0–100 for working patients and 0–80 for non-working patients. A clinical grade (excellent, good, fair, poor) was assigned based on the overall score [22]. General health was assessed using the EQ-5D-3L questionnaire [23, 24]. Each patient reported perceived pain, function, and general health for the periods before and after hardware removal during the same interview.

Sample size

A minimum of 11 patients undergoing hardware removal was deemed necessary to detect a clinically relevant mean change of 1.65 points (standard deviation 1.58) on the NRS for pain [25]. The required sample size for a clinically relevant change in function could not be determined, as the minimum clinically important difference (MCID) for the MPS has not been reported in the literature.

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics version 29 (IBM Corp., Armonk, NY, USA). Continuous data were tested for normality, and p-values < 0.05 were considered statistically significant.

Baseline characteristics of patients with and without hardware removal were compared using the chi-square test or Fisher's exact test for categorical variables, and the Student's t-test or Mann–Whitney U-test for continuous variables, as appropriate. Differences in NRS, MPS, and EQ-5D scores before and after hardware removal were analysed using the paired Student's t-test. Changes in clinical grade (excellent/good versus fair/poor), derived from the MPS before and after hardware removal, were tested using McNemar's test.

Results

Study population

In total, 116 patients were included. Their mean age was 62.1 years (standard deviation [SD] 21.7), and 76.7% were female. Most patients sustained low-energy trauma (59.5%), most commonly a fall from standing height (51.7%). According to the Young and Burgess classification, 84% of patients had lateral compression (LC)-type fractures.

Twenty-four of the 116 patients (20.7%; 95% confidence interval [CI] 13.7–29.2%) underwent hardware removal. This group was significantly younger than those without hardware removal (mean ± SD: 49.3 ± 20.1 vs. 65.4 ± 20.9; §< 0.05). No other significant differences in baseline characteristics were found between the two groups (**Table 1**).

Surgical parameters and complications

The median time to primary fixation was 5 days (range 0–145). In 94% of cases, the S1 corridor was used for percutaneous posterior screw fixation, and almost half of the cases had additional anterior ring fixation (46.6%) using either plate osteosynthesis or percutaneous retrograde or antegrade screw fixation (**Table 2**).

The number of transiliac–transsacral (TITS) screws was significantly higher in patients who underwent hardware removal ($p = 0.004$). Postoperative wound infection occurred in 2.6% of patients after primary surgery, and only one complication occurred after hardware removal surgery.

There were no cases of perioperative mortality. In total, five patients died during follow-up: in four, the cause of death was unknown, and one patient died from complications of chronic obstructive pulmonary disease (COPD) and heart failure more than two years after surgery (**Table 2**). None of these deaths were procedure related.

Hardware removal procedures

A total of 27 hardware removal procedures were performed in 24 of the 116 patients (20.7%). The median time from primary surgery to hardware removal was 241 days (range 9–826; **Table 3**). The primary reason for hardware removal was pain (51.9%). Fourteen procedures were performed because of pain, including one early postoperative case (<12 weeks); the remaining 13 were performed for chronic pain. Ten removal procedures (37.0%) were performed due to screw loosening diagnosed on follow-up radiographs. In nine of these cases, a transiliac–transsacral (TITS) screw was removed, while in one case, a sacroiliac (SI) screw was removed. Three procedures (11%) were indicated for nerve irritation related to narrowing of the S1 and S2 neuroforamina secondary to the initial fracture displacement, suggesting possible nerve root compression, although no screw malposition was identified. Of the 27 hardware removal procedures, one complication (3.7%) occurred, consisting of postoperative bleeding in the subcutaneous tissue requiring re-operation. The patient remained hemodynamically stable, and no blood transfusion was required.

Functional outcome after hardware removal

Of the 24 patients who underwent hardware removal, 19 (79%) completed the follow-up questionnaire. Three patients could not be reached by telephone consultation, one patient died during follow-up, and one patient could not complete the questionnaire due to insufficient language proficiency. The mean follow-up period after hardware removal was 16.3 ± 13.3 months.

As shown in **Table 4**, the mean pain score decreased from 5.6 ± 2.8 before hardware removal to 3.8 ± 3.0 (mean difference –1.8; 95% CI –3.0 to –0.6; $p = 0.005$). The Majeed Pelvic Score (MPS) improved significantly from 61.1 ± 20.9 to 74.6 ± 21.0 (mean difference 14.3; 95% CI 5.8–22.7; $p = 0.02$). Before hardware removal, more than half of the patients were graded as fair (21.1%) or poor (31.6%). After hardware removal, these proportions decreased to 15.8% and 10.5%, respectively, while the proportion of patients graded as excellent increased to 47.4%. Although this categorical improvement did not reach statistical significance ($p = 0.11$), the observed mean change of >14 points may be considered clinically relevant. Scores on both the EQ-5D index (mean increase 0.28; 95% CI 0.09–0.47; $p < 0.05$) and the EQ-VAS (mean increase 12.0; 95% CI 5.7–18.3; $p < 0.05$) improved significantly after hardware removal. Notably, the proportion of patients reporting no problems with mobility and no pain or discomfort nearly doubled after hardware removal (**Table 4**).

Discussion

In this single-centre cohort study, 20.7% of consecutive patients who were treated for a posterior pelvic ring fracture using 3D-navigated percutaneous screw fixation required hardware removal. Most removals were performed for chronic pain (81.5%), while a smaller number were due to mechanical or neurological complications. Hardware removal resulted in significant and clinically relevant improvements in pain and functional outcomes, with a low complication rate (3.7%). These findings suggest that selective removal in symptomatic patients can be beneficial, whereas routine removal in all cases is not justified [17, 18].

The significant improvements in NRS pain (–1.8 points), Majeed Pelvic Score (MPS) (+14 points), and EQ-5D observed in this cohort are consistent with previous studies [25]. Firoozabadi et al. reported pain relief and improved function in 88% of patients, while Gurnea et al. found a reduction in mean NRS from 4.9 to 0.5 after removal [18, 19]. Similarly, Quade et al. observed pain relief in 83% of cases. Although the degree of improvement in our cohort was slightly smaller, it remains clinically relevant and supports the hypothesis that hardware removal can alleviate residual postoperative discomfort. In contrast, McKibben et al. found no difference compared with controls, likely due to inclusion of asymptomatic or mixed-indication cases [16]. Despite overall improvement, a substantial proportion of patients continued to report limitations, including restricted mobility (52.6%) and persistent pain or discomfort (79%). Nevertheless, the significant improvements in EQ-5D and EQ-VAS scores indicate that hardware removal can meaningfully improve perceived general health.

Although the exact pathophysiological basis of screw-related pain remains uncertain, several mechanisms may explain pain improvement after hardware removal. The sacroiliac (SI) joint serves as a pivotal link between the spine and lower extremities, transmitting load between these regions. Although motion between the sacrum and ilium is minimal, the SI joint exhibits a limited range of motion (ROM) of approximately 3° in flexion–extension and 1.5° in rotation, with an average axial translation of about 0.7 mm, rarely exceeding 2 mm [26]. These small motions are essential for normal pelvic mechanics and load absorption.

With increasing age, degenerative changes such as osteoarthritis progressively reduce joint flexibility and motion [27, 28]. In contrast, younger patients typically exhibit greater sacroiliac mobility. In particular, younger patients undergoing rigid sacroiliac fixation with fully threaded screws may experience restriction of normal micromotion of the SI joint, potentially resulting in discomfort or pain. The restriction is particularly pronounced when both sacroiliac joints are bridged by a TITS, as bilateral fixation further limits physiological movement of the pelvic ring. Surgical removal of the screws can therefore restore limited physiological motion, relieve local mechanical irritation, and improve patient function, particularly in younger individuals.

Our findings support this concept, as the group who underwent hardware removal were significantly younger (49 vs. 65 years on average), and all but one of the removed screws were TITS screws bridging both SI joints rather than isolated SI screws.

Limitations

This study represents a real-world cohort encompassing both high- and low-energy trauma and various fixation configurations, reflecting the diversity encountered in clinical practice. Although this heterogeneity limits the ability to perform detailed subgroup analyses, it enhances the generalisability and clinical relevance of the findings. Several limitations must be acknowledged. First, the retrospective design introduces potential information bias, as missing or incomplete documentation may have led to under-reporting of minor complications or symptoms. Second, outcome data were collected via telephone interviews, which may have introduced recall bias. Third, the sample size of patients undergoing hardware removal was limited but still provided sufficient statistical power to detect both statistically significant and clinically relevant changes in outcomes. Finally, since hardware removal was performed only in symptomatic patients and not in asymptomatic individuals, a true control group was lacking.

Clinical implications

Based on these findings, clinicians should consider hardware removal in patients with persistent pain after radiographic fracture healing, once other causes such as malposition or nerve injury have been excluded. This is particularly relevant for younger patients and for patients with transiliac-transsacral screws traversing both sacroiliac joints. Pre-operative counselling should include discussion of the possibility of postoperative pain and the option of secondary hardware removal if symptoms persist.

Despite these observations, a general clinical consensus on this topic is still lacking, and post–sacroiliac screw fixation pain remains poorly understood [18]. In addition to pain directly related to screw fixation, sacroiliac pain may also be associated with sacroiliac joint (SIJ) dysfunction, a condition characterized by non-specific lower back pain radiating to the buttocks, groin, or thighs [29–31]. Moreover, pelvic trauma itself, including pelvic fractures, is a recognized cause of SIJ pain [30, 32–34].

The establishment of a larger, comprehensive database could facilitate the identification of factors associated with the occurrence of posterior pain and improve postoperative clinical decision-making. Furthermore, future studies should incorporate qualitative assessments of pain to better capture and address the individual experiences and needs of this patient population.

Conclusion

In conclusion, selective hardware removal after percutaneous 3D-navigated screw fixation of the posterior pelvic ring appears to be a safe procedure that can yield significant pain reduction and functional gains, especially in younger patients with persistent postoperative symptoms.

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Tables and figures

Table 1. Baseline characteristics of patients with and without hardware removal

	All patients *n* = 116	Hardware retained *n* = 92	Hardware removed *n* = 24	*p*
Age at time of trauma; mean (SD)	62.1 (21.7)	65.4 (20.9)	49.3 (20.1)	*0.001*
Age <65 years; n (%)	52 (44.8)	35 (38.0)	17 (70.8)	*0.05*
Female; n (%)	89 (76.7)	68 (73.9)	21 (87.5)	*0.16*
Trauma category; n (%)				*0.13*
Low Energy Trauma (LET)	69 (59.5)	58 (63.0)	11 (45.8)	
High Energy Trauma (HET)	47 (40.5)	34 (37.0)	13 (54.2)	
Trauma Mechanism; n (%)				*0.25*
Fall from standing height	60 (51.7)	50 (54.3)	10 (41.7)	
Fall from height (> 3m)	22 (19.0)	18 (19.6)	4 (16.7)	
Traffic accident	19 (16.4)	15 (16.3)	4 (16.7)	
Other mechanism or unknown	15 (12.9)	9 (9.8)	6 (25.0)	
Concomitant injury; n (%)	32 (27.6)	25 (27.2)	7 (29.2)	*0.85*
Young-Burgess classification; n (%)				*0.62*
APC type II	1 (0.9)	1 (1.1)	0 (0.0)	
APC type III	2 (1.7)	2 (2.2)	0 (0.0)	
LC type I	66 (56.9)	56 (60.9)	10 (41.7)	
LC type II	4 (3.4)	1 (1.1)	3 (12.5)	
LC type III	27 (23.3)	22 (23.9)	5 (20.8)	
Vertical Shear	5 (4.3)	4 (4.3)	1 (4.2)	
Combined	2 (1.7)	1 (1.1)	1 (4.2)	
Isolated sacral	9 (7.8)	5 (5.4)	4 (16.7)	

APC = anterior–posterior compression; LC = lateral compression; LET = low-energy trauma; HET = high-energy trauma; SD = standard deviation.

Table 2. Surgical parameters and complications

	All patients *n* = 116	Hardware retained *n* = 92	Hardware removed *n* = 24	*p*
Surgical fixation				
Time to primary surgery (days); median (range)	5.0 (0 – 145)	5 (0 – 145)	5 (1 – 137)	*0.98*
Temporary pelvic fixation; n (%)	19 (16.4)	15 (16.3)	4 (16.7)	*0.96*
Number of TITS screws; n (%)				*0.004*
0	13 (11.2)	9 (9.8)	4 (16.7)	
1	25 (21.6)	22 (23.9)	3 (12.5)	
2	71 (61.2)	59 (64.1)	12 (50.0)	
3	7 (6.0)	2 (2.2)	5 (20.8)	
Number of SI screws; n (%)				*0.88*
0	85 (73.3)	67 (72.8)	18 (75.0)	
1	13 (11.2)	11 (12.0)	2 (8.3)	
2	18 (15.5)	14 (15.2)	4 (16.7)	
Position of screws; n (%)				*0.61*
S1	109 (94.8)	86 (93.5)	23 (95.8)	
S2	63 (54.3)	63 (54.3)	15 (62.5)	
Additional anterior pelvic fixation; n (%)	54 (46.6)	40 (43.5)	14 (58.3)	*0.19*
Type of anterior fixation; n (% of total)				*0.38*
Plate	18 (15.5)	12 (13.0)	6 (25.0)	
Screw	36 (31.0)	28 (30.4)	8 (33.3)	
Complications after primary surgery; n (%)				*0.15*
Wound infection	3 (2.6)	3 (3.3)	0 (0)	
Nerve injury	4 (3.4)	1 (1.1)	3 (12.5)	
Screw loosening or malposition	11 (9.5)	3 (3.3)	8 (33.3)	
Malunion or non-union	2 (1.7)	1 (1.1)	1 (4.2)	
Chronic pain (>12 weeks)	29 (25.0)	11 (12.0)	18 (75.0)	
Total mortality; n (%)	5 (4.3)	4 (4.3)	1 (4.2)	*0.96*

TITS = transiliac–transsacral; SI = sacroiliac; SD = standard deviation

Table 3. Characteristics of hardware removal procedures

Hardware removal procedures	**n = 27**
Time from primary surgery to removal (months); median (range)	7.9 (0.3 – 27.1)
Reasons for removal; n (%)	
Pain	14 (51.9)
Postoperative (<12 weeks)	*1*
Chronic (>12 weeks)	*13*
Screw loosening	10 (37.0)
Nerve injury	3 (11.1)

Table 4. Pain, function, and health scores before and after hardware removal

n = 19	Before hardware removal	After hardware removal	*Mean Δ (95% CI)*	*p*
NRS pain score; mean (SD)	5.6 (2.8)	3.8 (3.0)	-1.84 (-3.1 – -0.6)	< 0.01
Majeed Pelvic Score (MPS), total; mean (SD)	61.1 (20.9)	74.6 (21.0)	14.3 (5.8 – 22.7)	< 0.01
MPS total (corrected); mean (SD)	66.2 (19.7)	80.4 (17.4	14.2 (5.6 – 22.8)	<0.01
Pain	15.8 (8.7)	21.6 (7.8)		
Work	8.2 (8.2)	11.00 (9.7)		
Sitting	6.2 (2.1)	7.2 (2.0)		
Sexual intercourse	3.6 (0.9)	3.8 (0.5)		
Standing: A Walking	11.1 (1.9)	11.6 (1.4)		
Standing: B Gait unaided	8.7 (3.2)	10.4 (2.2)		
Standing: C Walking distance	7.5 (2.7)	9.1 (2.7)		
MPS clinical grades (%)				0.11
Excellent	10.5	47.4		
Good	36.8	26.3		
Fair	21.1	15.8		
Poor	31.6	10.5		
EQ-5D-3L				
EQ-VAS; mean (SD)	57.9 (18.0)	69.9 (23.3)	12.0 (5.7 – 18.3)	< 0.01
EQ-5D index; mean (SD)	0.37 (0.42)	0.65 (0.38)	0.28 (0.09 – 0.47)	< 0.01
Dimensions (%)				
Mobility				
No problems	21.1	47.4		
Some problems	78.9	52.6		
Confined to bed	0.0	0.0		
Self-care				
No problems	57.9	78.9		
Some problems	31.6	21.1		
Unable to do	10.5	0.0		
Usual activities				
No problems	57.9	47.4		
Some problems	31.6	47.4		
Unable to do	10.5	5.3		
Pain				
No pain or discomfort	10.5	21.1		
Moderate or discomfort	36.8	57.9		
Extreme pain or discomfort	52.6	21.1		
Anxiety/depression				
Not anxious or depressed	36.8	68.4		
Moderately anxious or depressed	36.8	15.8		
Extremely anxious or depressed	26.3	15.8		

NRS = Numerical Rating Scale; MPS = Majeed Pelvic Score; EQ-VAS = EuroQol visual analogue scale; SD = standard deviation; Δ = difference; CI = confidence interval.

8

General discussion and clinical implications

General discussion and clinical implications

Pelvic fractures are relatively uncommon, accounting for approximately 2–8% of all fractures, but their incidence has increased over recent decades due to increased high-energy trauma and an aging population, resulting in more fragility fractures of the pelvis (FFP) [22, 51, 52]. While historically considered stable and managed conservatively, FFPs are now recognized as a distinct clinical entity with unique fracture patterns and mechanical instability. National guidelines, such as those of the Dutch Trauma Society (Nederlandse Vereniging voor Traumachirurgie, NVT), have increasingly acknowledged the clinical relevance of FFPs. However, well-defined treatment algorithms are still limited, and the optimal management strategy remains a topic of ongoing debate [53, 54].

The aim of this thesis is to address these challenges by examining surgical complications, optimizing treatment strategies for elderly patients with FFPs, and evaluating minimally invasive 3D navigated screw fixation, providing insights into both high-energy trauma and low-energy pelvic fractures.

Complications in pelvic fracture surgery

Mortality associated with high-energy trauma pelvic ring and/or acetabular fractures has been decreased through the increase in early and appropriate surgical and radiological interventions. Nevertheless, mortality rates remain substantial, ranging from 5 to 18% [55]. Although in the 21st century a high standard of antiseptic procedures and sterile surgical environments are well developed, particularly in Western countries, postoperative complications are still encountered after pelvic surgery in up to 35% of the patients.

A wide body of literature, including several textbook chapters, has described postoperative complications following pelvic ring and acetabular surgery. However, a comprehensive overview and insight into the specific complications associated with different surgical approaches was still lacking. **CHAPTER 3** provides a much-needed comparative overview of postoperative complications associated with different surgical approaches for pelvic ring and acetabular fractures. One of the most salient findings is the wide variation in reported complication rates, ranging from 5% in the Kocher–Langenbeck approach to 31% in external fixation, with the latter being particularly associated with superficial surgical site infections (SSIs) and neurological complications. A major strength of the review lies in its stratification of complications by surgical approach, allowing more nuanced clinical interpretation compared to prior reviews that pooled heterogeneous procedures. Furthermore, the inclusion of both retrospective cohort studies and one randomized controlled trial (RCT) enhance the breadth of evidence, although the predominance of lower-quality, non-comparative studies (as assessed by MINORS criteria) limits the robustness of any definitive conclusions. The findings highlight a significant gap in high-quality data regarding risk stratification.

Of the studies included in this review, only two reported potential predictors of SSIs, identifying high BMI, prolonged ICU stay, and concomitant abdominal injury as relevant factors. These findings suggest that patient characteristics may play a pivotal role independent of surgical technique.

In **CHAPTER 2**, obesity emerged as a major risk factor, with an odds ratio of 3.12 ($p = 0.01$), especially for postoperative infections. Obesity presents an increasing global health challenge associated with a wide array of health issues. Recent epidemiological data shows that obesity rates have continued to rise with over 40% of the adults in United States and in The Netherlands now classified as obese with Body Mass Index (BMI > 30 kg/m²). The current underrepresentation of such risk factor analyses underscores a missed opportunity in the current literature and emphasizes the need for prospective, multivariable-adjusted studies. Comparable to the data presented in **CHAPTER 2,** obesity also emerged as a major risk factor in **CHAPTER 3**, not only for postoperative wound infection but also for systemic complications such as deep venous thrombosis (DVT) and acute kidney injury (AKI). Obese patients had over three times the odds of developing an SSIs (OR 3.12), highlighting a vulnerable subgroup for whom additional perioperative precautions may be warranted. Similarly, the finding that each additional minute of operative time marginally increases the risk of SSIs (OR 1.01 per minute) underscores the clinical relevance of operative efficiency and the potential advantage of less invasive approaches when feasible.

Furthermore, obese patients are more likely to experience prolonged hospital and ICU stays, with an increased risk of extended mechanical ventilation requirements in polytrauma patients [56]. As epidemiological data indicated that nearly half of the population classifies as obese and therefore exposed to these increased risks, this growing problem must be addressed. Preventive measures to mitigate obesity-related complications should be implemented. Enhanced Recovery after Surgery (ERAS) protocols, which have been shown to mitigate these risks in general surgery, may also be beneficial in pelvic fracture surgery [57].

In **CHAPTER 2**, the percutaneous approach demonstrated the shortest average operative time and appeared to be associated with fewer infections, supporting its use in appropriate cases. However, its applicability is limited to less complex fracture patterns, and careful patient selection remains essential. Notably, while the rates of neurological and implant-related complications were relatively low, their potential to necessitate reoperation and impact long-term function reinforces the importance of surgical precision and postoperative surveillance. Despite its contributions, the study's retrospective design and single country setting limit causal inference and generalizability. The absence of long-term functional outcomes and quality-of-life measures also restricts the assessment of the true burden of complications beyond hospital discharge.

The combined findings of **CHAPTERS 2 and 3** confirm that SSIs are the most prevalent postoperative complication in pelvic fracture surgery and highlight obesity and prolonged surgery as modifiable risk factors. These findings support ongoing efforts to optimize surgical technique, reduce operative time, and tailor perioperative care to individual risk profiles.

Fragility fractures of the pelvis in elderly patients

Since 1900, the number of individuals over 70 years old has increased elevenfold, outpacing the threefold increase in the general population. By 2030, it is projected that one-quarter of the world's population will be over 65 years old [58, 59]. This trend is also evident in the Netherlands, where a similar increase in the incidence of FFP is observed [12]. As a result, awareness and research into the unique challenges of fragility fractures of the pelvis (FFP) have significantly expanded.

Professor Pol Rommens and his research group are the pioneers regarding these fractures, and their work has been vital in advancing our understanding in this area. In 2023, Rommens et al. introduced a novel classification system specifically tailored for geriatric pelvic ring fractures, recognizing the limitations of the existing classifications by Tile et al. and Young and Burgess, which are primarily designed for high-energy pelvic ring injuries [17, 32, 60]. Although the Rommens classifications provides a solid framework for understanding and classifying FFPs, the indications for operative treatment remain the subject of ongoing debate. In **CHAPTER 4,** a systematic review of the currently available literature regarding the indications for surgical fixation of FFPs demonstrated that the literature lacks large, well-designed (randomized controlled) trials. Nonetheless, there appears to be a growing consensus favouring fixation of FFPs, especially in patients who remain unable to bear weight due to pain following initial conservative management. Therefore, the primary goal of surgical interventions in these patients is to reduce pain levels and ambulate patients to levels at which they are able to mobilize from their beds either with or without walking adjuncts. This is in contrast to achieving anatomical reduction and the best functional outcome possible, which are strived for in young individuals with pelvic ring fractures.

The current literature advocates minimally invasive surgery, which is widely accepted as the preferred fixation technique in FFPs in elderly patients. Since the primary goal is to provide sufficient fracture stabilization to allow mobilization. As most of these fractures are not evidently displaced, achieving anatomical reduction through open approaches is considered seldom indicated. Moreover, as discussed in **CHAPTER 2 and 3**, minimally invasive screw fixation presents a low incidence of postoperative complications, especially wound infections, which are particularly concerning in frail elderly patients. The timing of surgery, i.e. the duration of the initial conservative treatment period, remains however, a subject of debate. No clear evidence for uniform agreement could be obtained from the currently available literature.

The multicentre prospective cohort study, detailed in **CHAPTER 5,** found that the majority (75.5%) of elderly patients with pelvic ring fractures had combined anterior-posterior pelvic injuries on routine CT scan evaluations upon presentation at the emergency department (ED). This percentage likely underrepresents the true incidence of posterior involvement, as advanced imaging techniques including dual-energy CT (DECT) and MRI reveal bone bruising indicative of posterior injury in 80%–95% of cases [61].

Conservative treatment, consisting of analgesia and supervised weight-bearing, was the standard initial approach, with surgery reserved for patients who failed to mobilize within the conservative timeframe. Despite the recommendations following Rommens' classification on which types of fracture to operate, only a small proportion of our cohort (4.9%) required surgical fixation, all of whom had FFP type II fractures. According to Rommens classification, FFP type II fractures are non-displaced anterior ramus superior/inferior fractures combined with a non-displaced unilateral fracture of the sacral ala and warrant surgical fixation when causing immobilizing pain. Remarkably, in our cohort, most of the patients had FFP II fractures and only one patient had a FFP type IV fracture. The latter did not suffer from immobilizing pain and therefore no surgical fixation was performed, which is in accordance with the consensus in the literature detailed in **CHAPTER 4**.

It is possible that the extent of posterior pelvic injuries was underestimated, as imaging was limited to routine CT scans rather than supplemented with DECT or MRI. Furthermore, as described in **CHAPTER 5,** most CT scans were obtained shortly after the initial trauma, potentially missing secondary displacement that can occur over time. For instance, an initially stable FFP type II fracture may progress to a more unstable type IV pattern during follow-up. In this study, follow-up CT scans were performed only when clinically indicated, such as worsening pain or impaired mobility. However, all patients were clinically monitored for one year, during which no significant deterioration in mobility or pain was observed. This suggests that fracture progression, if present, was minimal or clinically insignificant.

While Rommens et al. provide a robust classification system, we question the weight of the reliance on fracture classification for surgical decisions in elderly patients. In line with the literature and as described in **CHAPTER 4,** we believe that the decision on whether to operate should be based mainly on whether the patient is able to ambulate with acceptable pain scores, rather than be based on the observed fracture types. Furthermore, **CHAPTER 5** demonstrated no significant differences in mobility outcomes, pain scores, or mortality across the various fracture types. This strengthens the assumption that early surgery is not always needed and that a conservative treatment regimen can be safely started without increasing complications or mortality. The observed total mortality rate of 10% appears acceptable, for this elderly cohort with a mean age of 81.1 years (SD 7.6). Still, the optimal duration of conservative treatment and the appropriate timing to decide whether to operate remain unanswered. As stated in **CHAPTER 4**, the currently available literature also fails to provide solid guidelines or direction, as the duration of conservative treatment varied widely across studies.

Since the treatment decision in elderly seems not to be primarily based on the fracture type, we believe that performing routine CT-scan evaluations at initial presentation is redundant, especially when patients present shortly after a fall and before being subjected to an adequate pain regime. However, if patients present after several days of persistent pain, significant immobility or following unsuccessful conservative management, surgery may be considered. In such cases, a CT scan evaluation is recommended to determine if fracture progression has occurred causing the complaints and on the other hand for surgical planning purposes. Nevertheless, we strongly advocate for close monitoring and early follow-up, either in an institutionalized setting or at the outpatient clinic. As underlined in **CHAPTER 4** and supported by literature, pain levels are elevated, and patient mobility is reduced in the first weeks after trauma [62]. We consider this a natural consequence of the fracture itself. As long this does not lead to immobilizing pains levels and or bedridden this is acceptable. However, it is important to inform patients about the expected course of recovery and to provide explicit return instructions in the event of worsening pain or declining mobility, especially in these vital first weeks after trauma. Tailor-made and shared decision-making are crucial to ensure that treatment strategies align with the patients' specific needs and expectations.

Over the past years we have made considerable advancements in developing minimally invasive fixation techniques for pelvic fractures; techniques that are especially suitable to perform in this frail patient population. Still, only limited studies are available that focus on patient-reported outcomes (PROMs) and the remaining personal goals in life of this specific group [62]. When managing elderly patients with pelvic ring fractures, it is crucial to balance the risks of surgery and anesthesia with the patients' overall health status and comorbidities, while also considering their personal goals and quality-of-life expectations. Many elderly patients have complex medical conditions, and their remaining life aspirations should be included in the treatment decision-making. Non-surgical treatment, while potentially leading to immobility and early mortality, may still align best with a patients' preferences. Similar to the current evolution of non-surgical treatment of hip fractures, palliative pain management can offer meaningful relief and preserve dignity, even when surgical options are available.

There is growing reason to believe that the evaluation and management of pelvic ring fractures may evolve in a manner similar to that of hip fractures. An important distinction, however, is that hip fractures generally require surgical intervention to heal, and conservative treatment is almost always associated with the inability to mobilize followed by death. In contrast, as mentioned in **CHAPTER 4 and 5**, a substantial proportion of patients with an FFP can recover without surgical intervention and conservative treatment display significant healing potential and survivability. Still here are aspects that could be learned from. Beyond the life-threatening nature of hip fractures, surgery was traditionally also considered the only effective means of achieving adequate pain relief. However, in recent years, the treatment paradigm for hip fractures has shifted toward a more individualized and multidisciplinary approach. This modern strategy incorporates the patient's personal goals, frailty status, and comorbidity assessments, and emphasizes adequate pain control, including locoregional anesthesia, hip denervation, either in combination with palliative care, without necessarily resorting to surgery [63, 64].

We should learn from this evolution, by adopting a similar multidisciplinary strategy in the management of FFPs. This includes early involvement of geriatric specialists and a more selective surgical approach by identifying patients at high risk of early mortality following FFP surgery, particularly among frail elderly individuals, even when minimally invasive procedures are considered [65, 66].

Novel image guided screw fixation in pelvic surgery

Minimal invasive percutaneous posterior pelvic ring screw fixation originally described by Matta et al. in 1989, remains a widely used technique [67]. It involves navigating screws with a diameter of 6.5 mm through the narrow osseous corridors of S1 and/or S2 (approximately 14mm -17mm wide), guided by dual plane (2D) fluoroscopy [43]. However, the 3D positioning of these screws must be estimated by the surgeon based on 2D images, presenting significant challenges due to the complex anatomy of the sacrum. The characteristic angulated shape and narrow osseous corridors between the neuroforamina, all in close proximity to vital structures like sacral nerve roots and the sacral plexus make the sacrum a challenging area for screw fixation using 2D imaging, even for experienced pelvic surgeons. An aspect which could further complicate this procedure is the frequently observed sacral dysmorphism. Sacral dysmorphism is present in 41% of cases, resulting in more angulated and narrower osseous corridors, leading to an increased risk of cortical perforation and neurovascular damage [42]. Even skilled pelvic surgeons are known to encounter complication rates of up to 20% when performing conventional 2D percutaneous trans-iliac trans-sacral screw fixation [38].

Our neurosurgical colleagues in spine surgery faced a similar challenge. When performing spinal fracture fixation or spinal fusion inserting pedicle screws in the spinal vertebrae, comparable difficulties are encountered. The narrow osseous corridors of the spinal pedicles, comparable to those of the sacrum, pose similar risks of cortical screw perforation with potentially devastating consequences of iatrogenic spinal cord or nerve root injuries. In 1997, Merloz et al. published one of the earliest reports on computer tomographic (CT)-guided screw fixation in spinal surgery This article showcased a remarkable reduction in screw misplacement and related complications

[68]. Presently, CT- guided screw placement stands as the golden standard in spinal surgery. Despite the adoption of this technique by pelvic surgeons, it is noteworthy that even 26 years after the initial report of CT-guided screw fixation, conventional 2D fluoroscopic guidance remains widely accepted and used worldwide in pelvic ring surgery. Our study in **CHAPTER 6** illustrates the significant advantages of CT-guided 3D screw fixation, particularly in achieving a remarkably low screw misplacement rate of only 2.7%. This is a substantial improvement in procedural safety compared to the 20% screw misplacement rate reported in the literature. Importantly, in addition to improving screw placement accuracy, 3D-navigated fixation also enhances radiation safety for the surgical team. Radiation exposure during the procedure is minimal, as the surgical team briefly leaves the operating theater during theintraoperative CT scans. No additional fluoroscopy is required during screw insertion, as the procedure is guided by the scout CT-scan in combination with real-time 3D screw navigation. This represents a clear improvement over conventional 2D fluoroscopy-guided fixation, which requires continuous imaging and exposes the surgical team to higher radiation levels. Beyond clinical outcomes, we believe 3D screw navigation offers significant educational value, as mentioned in **CHAPTER 6**. In our institution, it has been successfully integrated into the training of residents, junior pelvic surgeons, and surgical team staff. The visual feedback and precision are especially valuable in the anatomically complex region of the sacrum, with minimal margins for error. The learning curve of 3D navigated screw fixation in sacral fractures also appears relatively short, with proficiency typically reached after 15–35 cases and near-perfect accuracy reported even among less experienced surgeons. In contrast, 2D-guided screw fixation likely requires 40–70 screws to achieve consistency, with misplacement rates of up to 20% persisting even in experienced hands. These observations support that 3D screw navigation in pelvic ring surgery should not only be seen as a technological upgrade to enhance procedural safety but also as an essential tool to enhance education in pelvic trauma surgery.

The major downside of this technique is the potential costs and therefore the general availability. We are aware that 3D guided navigations systems may not be available in every hospital due to the high costs associated with acquiring these set ups. However, we believe that pelvic surgery is already a highly specialized form of surgery and is typically centralized in specialized centres, usually (academic) level 1 trauma centres. In these centres, there is usually a co-existence of neurosurgical and spinal trauma surgical specialties. The potential high cost involved in the acquisition and maintenance of 3D navigation systems system could be shared between the pelvic trauma and spinal trauma specialist groups as a joint venture. From a cost-effectiveness perspective, the use of a 3D navigation system is associated with a short operative time, particularly when performed by a dedicated surgical team. In addition, the relatively quick learning curve and improved accessibility of this technique offer further advantages, enabling more efficient use of operating time and personnel allocation, which can ultimately contribute to greater overall cost efficiency. However, robust literature on this topic is lacking, and further research is necessary to substantiate these suggestions.

Although the introduction of minimal invasive techniques and improved percutaneous screw navigation mitigated the risk on surgical site infections and screw misplacement rates complication remain prevalent. Common complications after percutaneous screw fixation after especially the posterior pelvic ring are persistent pain and secondary screw loosening and are of clinical relevance as they often need secondary interventions. **CHAPTER 7** addresses these issues by analysing the indications for screw removal in a mixed cohort of patients who underwent percutaneous screw fixation for both high- and low energy pelvic ring fractures. In the cohort of 116 patients, hardware removal was performed in 21% of the patients, a relatively high proportion that underlines the clinical impact of these complaints. The main indications for screw removal were persistent pain (52%), followed by screw loosening (37%). The subgroup reporting persistent pain were predominantly younger individuals, and younger age was also determined as an independent risk factor for screw removal. The underlying cause of the age-related trend remains speculative. A possible explanation is that the movement within the sacroiliac (SI) joint is more prominent in younger patients. Percutaneous trans iliac trans sacral (TITS) screw fixation stabilizes the sacral fractures but inherently eliminates these subtle joint movements, as the screws transverse the SI joint. After the fracture is healed, this restriction may result in abnormal joint stress subsequently leading to pain or discomfort. However, it remains difficult to differentiate whether the pains are caused by the screw fixations, residual trauma induced changes or by the onset by post-traumatic osteoarthritis of the SI-joint. Despite these diagnostic uncertainties, our data reveals a significant reduction in pain scores and an improvement of mobility scores following screw removal. This suggest that in at least a subset of patients the hardware itself contributes to the symptoms.

Based on the finding of **CHAPTER 7** and the clinical observation and experience we tend to be more deliberate towards screw removal, particularly in younger patients presenting with persistent SI joint related pin. Our current clinical algorithm favors early screw removal especially in younger individuals with symptoms location and hardware positioning exist. The decision to favor screw removal is supported by the significant decrease in pain and the low complication rates as described in **CHAPTER 7**. Diagnostic CT-scan evaluations is usually performed to rule out any residual fracture instability or fracture progression. Furthermore, a useful intermediated diagnostics step involves image guide intra-articular SI joint injection with local anesthetics, administered by a pain specialist. If the patients experience temporary symptom relief following the injections it suggests that the SI joint is the primary cause of pain whereas other factors e.g. myogenic pain or postoperative wound and scar tissue are less likely to be the predominant sources of symptoms. However, at this point it remains a challenge to differentiate between screw-related pain and the (early) onset of SI joint osteoarthritis, as both may temporarily respond to the intra-articular local anesthesia injection. Despite the diagnostic uncertainty, hardware removal is generally performed as the initial step. If symptoms persist even following screw removal, the likelihood of underlying SI joint osteoartitis increases. Further workup may include provocation tests during physical examination, as well as imaging techniques such as MRI or SPECT-CT scan to evaluated degenerative changes. It is important to state that the current clinical practice, including our own, is still primarily based on clinical experience and expert opinion. Further research into the underlying cause of this complex and not yet well-understood, frequently encountered problem is paramount.

The other frequently encountered complication after percutaneous posterior screw fixation is screw loosening. Several possible explanations of screw loosening have been proposed, including loss of grip of the implant because of reduced bone quality, insufficient implant stability, or persistent instability of pelvic ring due to unaddressed anterior pelvic ring fractures. Notably, in the cohort presented in **CHAPTER 7,** all but one of the screws removed due to loosening were trans-iliac trans-sacral screws (TITS) in primarily Lateral Compression type I (LC-I) fractures. The mean age of patients undergoing hardware removal was 49.3 years (SD 20 years), indicating that screw loosening occurred in relatively young individuals who would generally be expected to have adequate bone quality and therefore sufficient screw purchase. TITS screws are typically considered biomechanically more stable compared to SI screws [69, 70]. This raises the possibility that residual instability of the pelvic ring, rather than implant quality alone may be the cause of screw loosening.

The question whether to additionally fixate the anterior pelvic ring after initial posterior pelvic ring screw fixation remains a subject of ongoing debate. This applies both to LC-I factures in younger patients and to FFPs in elderly patients. In clearly unstable fractures patterns, such as the LC-II, LC-III and vertical shear (VS), combined anterior-posterior stabilization is essential to achieve adequate stability. This is supported by the World Society of Emergency Surgery (WSES) guidelines [2, 71].

However, it remains unclear whether LC-1 and low energy pelvic ring fractures in elderly, particularly. FFP type II, require routine anterior fixation in addition to posterior fixations. The main challenges lie in accurately assessing the residual instability of these fractures following posterior fixation.

Similar challenges persist when evaluating the in initial degree of in stability in LC-1 fractures. While these fractures are often regarded as stable and treated non-operatively, recent literature suggests they constitute a heterogenous group with a wide range of instability profiles. Clinicians continue to struggle in reliably identifying truly unstable injuries in this subgroup and, consequently, determining which patients may benefit from surgical intervention. To support clinical decision-making, several diagnostics tools are being utilizes, including stress testing under anesthesia (Examination Under Anesthesia, EUA). This dynamic method involves applying anteroposterior (AP) force to assess pelvic ring instability. If displacement greater than 1cm is observed during EUA, it is considered a strong prediction of pelvic ring instability and thus an indication for surgical fixation. However, the technique is subject high interobserver variability, underscoring the need for more objective and reproducible assessments methods [72-75]. The EUA principle could potentially be repurposed to assess residual pelvic ring instability, following posterior fixation in FFPs fracture in elderly. For example, if continued anterior displacement is observed during stress testing after posterior ring fixation, this may justify supplemental anterior fixation. In addition to diagnostic uncertainty of additional fixation of FFPs in elderly, the decision to pursue anterior fixation is also shaped by the anatomical and surgical limitations.

The main reasons to refrain from additional anterior fixation after initial posterior fixation of FFPs include persistent displacement of pubic rami fractures or anatomical constraints that prevent percutaneous screw placement (e.g. curvature of superior pubic ramus). In such cases, when percutaneous reduction is not feasible, open reduction would be required. This is often considered undesirable in this frail patient population due to the presumed higher risk of post-operative complications [76, 77]. However, robust evidence to support the practice of refraining from open reduction in these frail elderly is still lacking. Novel devices such as the CurvaFix implants have been developed specifically for treating FFPs in elderly patients [78, 79]. Unlike conventional rigid screws, this flexible implant is primarily designed to conform to the natural curvature of the sacral corridors thereby reducing the risk of cortical perforation and facilitating the placement of longer and wider implants, potentially improving biomechanical stability [78, 80]. Recent reports by the designers and key users have also described the use of these implants in the fixation of superior pubic ramus fractures, mitigating the technical difficulty of inserting straight rigid screws into curved or narrow ramus anatomy. These developments, in combination with improved methods for assessing residual instability, may lower the threshold for performing additional anterior ring fixation using minimally invasive techniques, thereby allowing surgeons to confidently pursue additional anterior stabilization especially in frail elderly.

Future perspectives

Many challenges in pelvic fracture surgery have been addressed thanks to the development and refinements of fracture fixation techniques, peri-procedural safety, and advances image-guided navigation. However, despite these technological improvements, several key challenges persist and continue to demand attention.

Robust, high-quality research is needed to deepen our understanding of these complex fractures and improve management strategies. Currently, uniform and comparable data on patient characteristic, outcome measures, and study especially patient-reported outcomes (PROMs), remain limited still lacking in the pelvic fracture literature. Establishing a Dutch national registry for pelvic and acetabular fractures could significantly reduce the heterogeneity found in the existing literature. This would, in turn, enhance the quality of research for pelvic fracture in general and more specific for the emerging entity of fragility fractures of the pelvis (FFPs). The newly initiated Dutch national PRO-PELVIS, as well as the and the international AO-Fragility Fractures of the Pelvis (AO-FFP) registry, holds significant promise for advancing our understanding of these injuries. [33].

A second area of focus should be the broader implementation of 3D navigation systems for percutaneous screw fixation in pelvic fractures. This technology has demonstrated the potential to significantly reduce complication rates, as it offers a substantially higher degree of safety compared to the conventional 2D fluoroscopic techniques. Moreover, the real time visual feedback offered during the procedure provides invaluable educational advantages for surgical residents and junior pelvic surgeons. Looking ahead, emerging technologies such as augmented reality and advanced visualization tools also hold great promise for improving intra-operative guidance. However, these innovations remain largely untested in clinical settings, with current evidence confined to ex vivo studies. [81].

Perhaps the most crucial area for future progress lies in the development of better decision-making tools with respect to which patient to operate, especially in elderly frail patients. Artificial intelligence (AI)-driven clinical decision support systems have already shown promising results in predicting fractures instability in areas such as distal radius fractures [1]. Similar AI-based models tailored to pelvic ring fractures could help identify which (elderly) patients would truly benefit from surgical intervention. The availability of big data from national and international registries will be instrumental in developing such predictive tools. These large datasets can yield critical insights into patient characteristics, post operative outcomes and complication risk thereby enabling more individualized treatment planning and support the development of AI- supported risk prediction.

While emerging technologies such as 3D navigation, AI and big data driven tools promise safer and more precise care, they cannot replace the need for careful clinical judgment. The foundation of high-quality surgical care most continues to rely on thorough clinical evaluation, shared decision making and multidisciplinary collaboration. Ultimately, surgery is not governed solely by algorithms, it is shaped by clinical reasoning, surgical experience, and a commitment to patient-centred care.

Clinical implications

- Routine initial CT-scan imaging in geriatric pelvic ring fracture at the emergency department (ED) should be de-implemented. Most FFPs diagnosed on plain radiographs heal successfully when treated conservatively (pain reduction and mobilization). The presence of additional posterior pelvic ring fracture does not predominantly dictate the treatment regime

- Persistent pain preventing full weightbearing is an indication for surgical fixation of pelvic ring fractures in geriatric patients.

- Short-term follow-up of elderly patients with pelvic ring fractures that are treated non-operatively is essential, since a selection will benefit from delayed surgery.

- Percutaneous 3D navigated screw fixation appears to offer superior safety and accuracy compared to conventional 2D fluoroscopic navigations in trans-iliac trans-sacral (TITS) screw fixation of the pelvic ring and may be considered a preferred approach in suitable settings.

- Screw removal is necessary in approximately 21% of patients following percutaneous screw fixation of the posterior pelvic ring, particular in younger patients experiencing persistent pain. This may be attributed to the higher mobility of the sacroiliac joint in this population, necessitating closer post-operative monitoring and clinical awareness of potential hardware-related discomfort.

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9

General Summary

General summary

Pelvic ring fractures represent a complex spectrum of injuries, the characteristics and outcomes are influenced by several factors such as trauma mechanism, bone quality, patient age, and comorbidities. Although relatively rare compared to other type of fracture, the clinical significance of pelvic fractures is substantial, especially given the increasing incidence over recent decades driven by both high-energy trauma and the growing number of low-energy fragility fractures of the pelvis (FFP) in the elderly patients. As outlined in **CHAPTER 1**, this thesis aims to identify and address the current challenges in pelvic fracture surgery. It explores the complications associated with their treatment, evaluating optimal management strategies for FFPs in elderly patients, and assessing the safety and clinical applicability of minimally invasive and 3D image-guided screw fixation techniques.

Part I: complications in treatment of pelvic ring fractures

The first part of this thesis focusses on the complications following pelvic fracture surgery. Despite modern surgical advances, postoperative complications are still high and can rise to 35%, with surgical site infections (SSI) being the most prevalent. In **CHAPTER 2**, a retrospective cohort study identifies obesity and prolonged operative time as the most relevant risk factors. The systematic review in **CHAPTER 3** confirms these finding and emphasizes that minimally invasive approaches reduce SSI rates and operative duration, which is particularly beneficial in frail (elderly) patients. These chapters highlight the need for further research into better risk assessments and targeted preventive strategies.

Part II: treatment strategies for pelvic ring fractures in elderly patients.

The second part of the thesis focuses on treatment strategies for elderly patients with pelvic fractures better known as FFPs. A systematic review in **CHAPTER 4** found there is increasing support in the current available literature to perform surgical fixation of FFPs in elderly patients who fail to mobilize due to pain after initial conservative treatment. Minimally invasive fixation techniques such as percutaneous screw fixation are favored with the primary aim to restore mobility rather than achieve anatomical reduction. **CHAPTER 5** presents a prospective multicentre study showing that the majority (75.5%) of elderly patients have combined anterior-posterior pelvic fractures on routine CT-scan evaluation. The study finds no significant differences in pain, mobility, or mortality across fracture types, reinforcing that surgical decisions should be driven by functional status rather than fracture classification. Therefore, routine CT scan evaluation at initial presentation is unnecessary especially if performed early without adequate pain control. However, strict follow-up of these patients and additional CT imaging on indication is recommended to detect fracture progression especially when pain or immobility persist.

Part III: minimal invasive screws in pelvic ring fractures.

The final part explores advances in minimally invasive 3D navigated screw fixation in pelvic fracture surgery. Enhanced intraoperative imaging and CT guided screw navigation has improved surgical precision, reducing risks of screw misplacement and on iatrogenic neurovascular injury in the complex pelvic anatomy.

CHAPTER 6 demonstrates the safety and accuracy of 3D navigated screw fixation for pelvic fractures, in a consecutive patient series. Minimal screw misplacement (2.7%) and no neurovascular injuries are reported, an evidently improvement when compared to conventional 2D fluoroscopy navigated screw fixations. **CHAPTER 7** evaluates the indications for hardware removal after percutaneous screw fixation of the pelvis. It found that 21% of the patients needed screw removal after percutaneous pelvic screw fixation, mainly due to pain (52%) and screw loosening (37%). Especially younger patients are more affected, likely because of high mobility in the sacroiliac joint. Screw removal improved pain and mobility significantly. However, determining which patient will benefit from screw removal remains a challenge highlighting the need for better diagnostic pain differentiation methods.

In conclusion, **CHAPTER 8** brings together the main insights from the thesis, focusing on the growing number of pelvic ring fractures and it current associated challenges. It reflects on the challenges in diagnosing and treating FFPs in elderly after low-energy trauma. Initial CT scans seem redundant since treatment decisions are mainly based on clinical features rather than fracture characteristics. However closely monitoring and follow-up is of upmost importance since these types of fractures can progress over time and the patient's condition can deteriorate. Advancements in surgical technique especially the use of less invasive and 3D CT-guided screw navigations techniques are showing superior results and becoming more common but are still not belonging to the standard treatment. The discussion stresses the need for further implication of these navigation techniques, development of tailored patient centred approach, and development of uniformal and consistent treatment protocols.

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Dutch Summary
(Nederlandse samenvatting)

Dutch Summary (Nederlandse samenvatting)

Bekken- en acetabulumfracturen vormen een complex spectrum van letsels, waarvan de kenmerken en uitkomsten worden beïnvloed door diverse factoren zoals het traumamechanisme, de botkwaliteit, de leeftijd van de patiënt en de comorbiditeiten. Hoewel bekkenfracturen relatief zeldzaam zijn in vergelijking met andere fractuurtypen, is hun klinische relevantie aanzienlijk. De incidentie is de afgelopen decennia toegenomen, waarbij de grootse stijging wordt gezien in laag-energetische fragiliteitsfracturen van het bekken (FFP's) bij oudere patiënten. Zoals beschreven in **HOOFDSTUK 1**, heeft dit proefschrift als doel de huidige uitdagingen binnen de bekken en acetabulum chirurgie te identificeren en te adresseren. Het onderzoekt de complicaties die samenhangen met de operatieve behandeling, evalueert optimale behandelstrategieën voor FFP's bij oudere patiënten, en richt zich op de veiligheid en klinische toepasbaarheid van minimaal invasieve en 3D-genavigeerde schroeffixatie.

DEEL I: Complicaties bij de behandeling van bekkenringfracturen

Het eerste deel van dit proefschrift richt zich op de complicaties na operatieve behandeling van bekken en acetabulumfracturen. Ondanks moderne chirurgische innovaties blijven postoperatieve complicatiepercentages hoog en kunnen deze oplopen tot 35%, waarbij postoperatieve wondinfecties (SSIs) het meest voorkomen.

In **HOOFDSTUK 2** wordt in een retrospectieve cohortstudie vastgesteld dat obesitas en een verlengde operatieduur de meest relevante risicofactoren zijn voor het ontwikkelen voor SSIs. De systematische review in **HOOFDSTUK 3** bevestigt deze bevindingen en benadrukt dat minimaal invasieve benaderingen het infectierisico en de operatieduur verminderen, wat met name bevorderlijk is bij kwetsbare (oudere) patiënten. Deze hoofdstukken benadrukken de noodzaak van verder onderzoek naar betere risicobeoordelingen en gerichte preventieve strategieën.

DEEL II: Behandelstrategieën voor bekkenfracturen bij ouderen

Het tweede deel van het proefschrift richt zich op behandelstrategieën voor oudere patiënten met bekkenfracturen, beter bekend als fragiliteitsfracturen van het bekken (FFP). Een systematische review in **HOOFDSTUK 4** toont aan dat er in de huidige literatuur consensus is voor operatieve fixatie bij oudere patiënten die, ondanks een initiële conservatieve behandeling, niet kunnen mobiliseren vanwege pijn. Minimaal invasieve fixatietechnieken, zoals percutane schroeffixatie, hebben hierbij de voorkeur. Het primair doel van de behandeling bij deze groep patiënt is het herstellen van mobiliteit in plaats van anatomische reductie van de fractuur. **HOOFDSTUK 5** beschrijft een prospectieve multicentrische studie, waaruit blijkt dat het merendeel (75,5%) van de oudere patiënten op routinematige CT-scans gecombineerde anterieure-posterieure bekkenfracturen vertoont. De studie vond geen significante verschillen in pijn, mobiliteit of mortaliteit tussen de groepen met geïsoleerd anterieure bekkering fractuur of de gecombineerde anterieure-posterieure bekkenfracturen. Dit bevestigt dat de indicatie voor chirurgische fixatie van FFP primair gebaseerd moeten worden op de functionele status van de patiënt en niet op de fractuurclassificatie. Daarnaast lijkt routinematige CT-scan evaluatie bij de initiële presentatie niet noodzakelijk, zeker niet wanneer deze vroeg wordt uitgevoerd zonder adequate pijnstilling. Strikte follow-up en aanvullende beeldvorming op indicatie blijven echter essentieel om fractuurprogressie tijdig te detecteren, vooral wanneer pijn of immobiliteit aanhoudt.

DEEL III: Minimaal invasieve schroeffixatie bij bekkenringfracturen

Het laatste deel van het proefschrift spits zich toe op minimaal invasieve, 3D-genavigeerde schroeffixatie bij bekkenfracturen. Verbeterde intra-operatieve beeldvorming en 3D-genavigeerde schroeffixatie hebben de chirurgische precisie verhoogd en het risico op verkeerd geplaatste schroeven en daardoor iatrogene neurovasculaire letsels in de complexe bekkenanatomie verminderd.

HOOFDSTUK 6 toont in een patiënten serie de veiligheid en accuraatheid aan van 3D-genavigeerde schroeffixatie bij bekkenfracturen. Er werd een minimaal percentage schroefmalpositie (2,7%) en geen neurovasculaire complicaties vastgesteld. Dit is een duidelijke verbetering ten opzichte van conventionele 2D-fluoroscopisch genavigeerde percutane fixaties. **HOOFDSTUK 7** evalueert de indicaties voor het verwijderen van osteosynthesemateriaal na 3D genavigeerde percutane schroeffixatie van het bekken. Bij 21% van de patiënten was schroef verwijdering noodzakelijk, voornamelijk wegens pijn (52%) en schroefloslating (37%). Vooral jongere patiënten bleken vaker klachten te hebben, waarschijnlijk door een hogere mobiliteit van het sacro-iliacale gewricht. Het verwijderend van het osteosynthese materiaal leidde tot een significante verbetering van pijn en mobiliteit. Het blijft echter een uitdaging om vooraf te bepalen welke patiënten baat zullen hebben bij materiaalverwijdering, wat de noodzaak benadrukt van betere diagnostische methoden voor het vaststellen van de herkomst van pijn.

In **HOOFDSTUK 8** worden de belangrijkste inzichten uit dit proefschrift samengebracht, met aandacht voor de toename van bekkenringfracturen en de daarbij behorende uitdagingen. Het hoofdstuk bespreekt de uitdagingen bij de diagnose en behandeling van FFP's na laag-energetisch trauma bij ouderen. Routinematige CT-scans lijken vaak overbodig, aangezien behandelbeslissingen vooral worden bepaald door klinische kenmerken in plaats van fractuureigenschappen. Nauwgezette follow-up blijft echter van groot belang, aangezien deze fracturen in de loop van de tijd kunnen progressief instabiel worden en de conditie van de patiënt kan verslechteren.

De vooruitgang in chirurgische technieken van met name het gebruik van minimaal invasieve en 3D-gestuurde navigatietechnieken, toont veel belovende resultaten en wordt steeds vaker toegepast, maar behoort nog niet tot de standaardbehandeling.

De algemene discussie benadrukt de noodzaak van verdere implementatie van deze navigatietechnieken, de ontwikkeling van een patiëntgerichte, op maat gemaakte benadering, en het streven naar uniforme en consistente behandelprotocollen.

Appendices

Curriculum Vitae

Robert A. Timmer was born on 16 January 1994 in Heemskerk, The Netherlands. He completed his secondary education (VWO) at Luzac College Haarlem in 2012. Prior to commencing his medical studies, he was a member of the Dutch national sailing team and competed in multiple national and international regattas in the Laser class, including participation in the 2010 Laser Radial Youth World Championship held in Largs, Scotland.

After not being selected in the initial medical school selection procedure, he spent a year studying International Business in Boston, United States. In 2013, he returned to the Netherlands and enrolled in the Medicine programme at Leiden University Medical Center (LUMC), obtaining his medical degree in 2019.

During his medical studies, he became actively involved in several extracurricular activities, including the organisation of the European Summer School of Trauma and Emergency Surgery (ESSETS). During his Bachelor's studies, he developed an interest in scientific research and became involved in research projects under the supervision of prof. dr. I.B. Schipper and dr. S.A.G. Meylaerts. This included the initiation of the PICTURE study, a prospective cohort study investigating the clinical relevance of additional posterior pelvic ring fractures in elderly patients.

These research activities ultimately marked the beginning of his academic career and subsequently led to the start of his PhD trajectory in 2022 at LUMC, entitled *Clinical Challenges and Innovations in the Treatment of Pelvic Fractures*, which he conducts alongside his surgical residency.

After obtaining his medical degree, he began his clinical career as a surgical resident (ANIOS) at Haaglanden Medical Center (HMC) in The Hague and subsequently at Leiden University Medical Center (LUMC). In 2023, he started his surgical residency training (AIOS) at Haaglanden Medical Center (HMC), where he is currently in training. His subspecialization in trauma surgery is expected to begin in 2027.

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Professor Schipper, beste Inger, Na mijn wetenschapsstage klopte ik bij je aan met de wens om verder te gaan met wetenschappelijk onderzoek binnen de traumachirurgie. Het is een lang traject geweest, maar dankzij jouw vertrouwen en begeleiding is dit proefschrift een passend einde. Veel dank voor alles.

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Wetenschaps(stage) studenten Diederik, Erdem, Robert, Kim en Cassidy: Zonder jullie ondersteuning was dit proefschrift niet tot stand gekomen. Het begeleiden van jullie was een voorrecht. Ik heb veel geleerd van jullie frisse blik en kritische houding — hopelijk was dat wederzijds

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Chirurgen van het HMC, Als 'kind van het HMC' begon mijn chirurgische carrière hier met mijn coschappen, gevolgd door de semiartsstage, het ANIOS-schap en nu mijn opleiding tot chirurg. Dank voor het in mij gestelde vertrouwen. Ik beschouw jullie als voorbeeld en ben zeer dankbaar en trots dat ik door jullie word opgeleid.

Collega-Assistenten, AIOS en ANIOS-chirurgie HMC, Veel dank voor jullie inzet en bijdrage aan de inclusie voor de studies. Daarnaast dank voor de mooie momenten, het aanhoren van mijn gespui in de assistentekamer en uiteraard tot in de Boterwaag.

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