The wrist and scapholunate ligament dysfunction

Dealing with biomechanics, diagnosis, and treatment

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THE WRIST AND SCAPHOLUNATE LIGAMENT DYSFUNCTION

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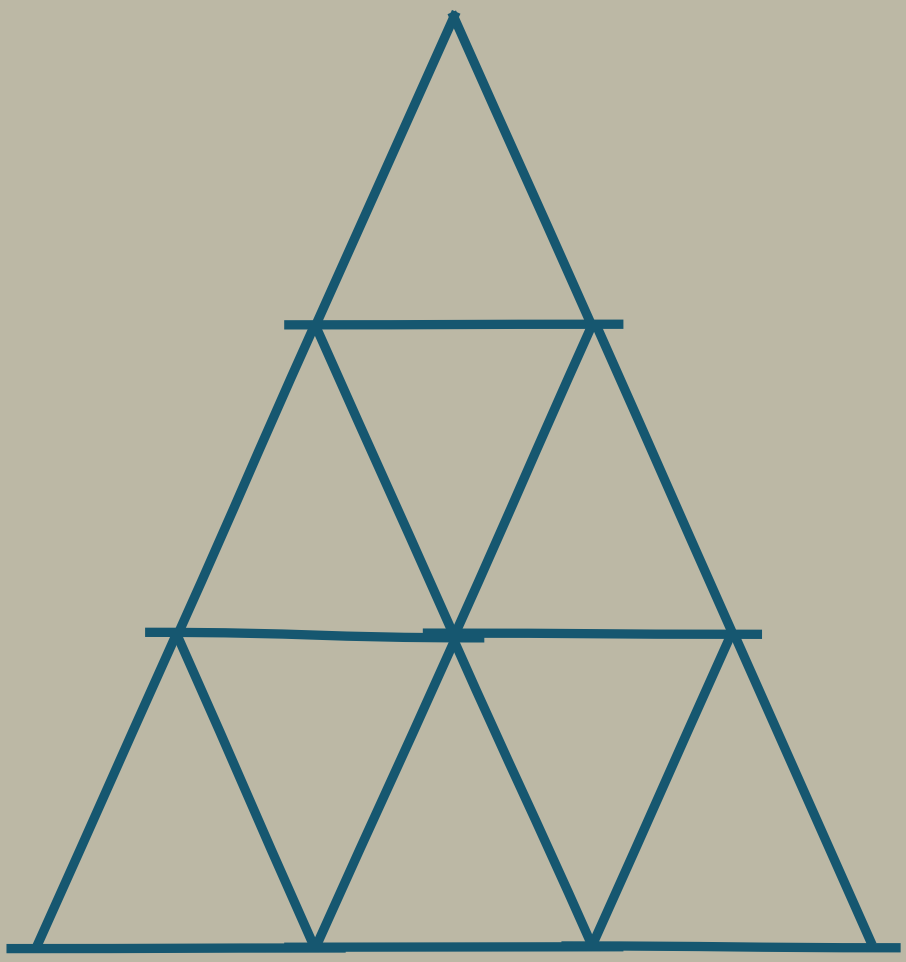
1 Introduction



1.0 The human hand and wrist

1.1 Introduction

The human hand and wrist play an important role in everyday activities, enabling tasks such as gathering information, handling objects, communicating, engaging work, artistic expression and many more. Notably, the hand and wrist possess the highest concentration of joints compared to other body regions.[1] To execute these various functions while maintaining stability, complex coordination between bones, muscles, nerves and ligaments is needed. The wrist can be compared to a house of cards: well aligned, but unstable to some extent. The balance between stability and alignment, and the involvement of many structures make the wrist a complex joint. Injuries that affect those structures can disrupt wrist function and might lead to the collapse of the house of cards.

The complexity of the wrist, the unclear natural progression of injuries, the difficulty of diagnosing and the lack of high evidence research make surgical intervention and subsequent rehabilitation complicated.[2]

1.2 Historical perspective

For many years, dissection of the human body was restricted due to religious believes, cultural traditions and limited recourses. These circumstances let Hippocrates (460 –377 B.C.), who is seen as the founder of Western medicine, and Aristotle (384-322 B.C.), rely solely on animal dissection for the study of anatomy.[3] Although human dissection was prohibited within the Greek borders, it was allowed to be performed in conquered territories, like in Alexandria, Egypt. This resulted in an influential medical school and library of Alexandria (founded by Alexander the Great in 332 B.C., when he was just 24 years old). It is believed that Herophilus and Erasistratus, both living in Alexandria, were among the first to dissect human bodies resulting in two complete human skeletons.[4] These skeletons, observations of wounded gladiators and dissection of animals (especially apes) inspired Galen (Galenus) to write '*De anatomicis administrationibus*', which was one of the first important anatomical works describing hand and wrist anatomy.

During the following Middle Ages (400-1400 A.D.), minimal progress in anatomical knowledge was made. Above all, big fires destructed medical books in Alexandria, including the works of Herophilus and Erasistratus.[3] Throughout the dark ages human anatomy was mainly influenced by Galen's work. It was not until the Renaissance, when in 1543 Vesalius published '*De Humani Corporis Fabrica Librii Septum*'. This atlas included detailed hand and wrist drawings derived from his personal dissection sessions on humans. These dissections demonstrated that Galen's work was mostly influenced by animal anatomy which not always corresponded with human anatomy.[4,5] It started an anatomical revolution, followed

by centuries in which several eponyms such as Camper (chiasm of Camper, 1760), Struthers (ligament of Struthers, 1854), Gyon (Gyon's canal, 1861), Lister (Lister's tubercle, 1865), Frohse (Arcade of Frohse, 1908) became an integral part of upper extremity anatomy and are still being used.[4] Just after the invention of X-ray by Röntgen (1895), the first description of scapholunate dissociation appeared by the French clinician Etienne Destot who frequently used this new invention (notable is that he had to stop his practice due to severe radiation damage to his own hands).[6] After the First- and Second World War, the research into the scapholunate interval and its instability regained attention.[7,8] The studies performed in the 80's and 90's are still providing the basis for ongoing developments today.

2.0 Anatomy

2.1 Bones

The anatomy of the hand and wrist can be subdivided into the wrist, the metacarpals and the five digits. The wrist is composed of the distal radius, the distal ulna, the eight carpal bones organized in a proximal and distal row, along with the five metacarpals. Moving from the radial to the ulnar side the proximal row comprises the scaphoid, lunate, triquetrum and pisiform. The distal row includes of the trapezium, trapezoid, capitate and hamate. While the distal row has attachments of muscle tendons, the proximal carpal row lacks any muscle attachment. The absence of direct muscle insertions results to the inability to move independently. For this reason, the proximal row is sometimes referred to as the intercalated segment.[9]

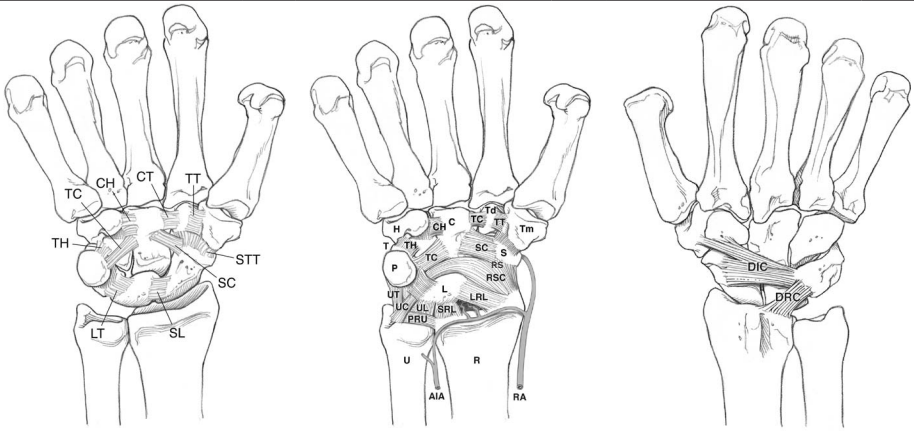
2.2 Muscles

At the palmar side, the radiocarpal and ulnocarpal joints are crossed by tendons of the m. flexor carpi radialis (FCR), m. palmaris longus (FPL), m. flexor carpi ulnaris (FCU), m. digitorum superficialis FDS), m. flexor digitorum profundus (FDP), m. flexor pollicis longus (FPL). At the dorsal side the tendons of the m. extensor pollicis brevis (EPB), m. abductor pollicis longus (APL), the m. extensor carpi radialis longus (ECRL), m. extensor carpi radialis brevis (ECRB), m. extensor pollicis longus (EPL), m. extensor digitorum communis (EDC), m. extensor indicis propria (EDI), m. extensor digiti minimi (EDM) and m. extensor carpi ulnaris (ECU) cross the radiocarpal and ulnocarpal joint.

2.3 Ligaments

The ligaments of the wrist are categorized into two groups: intrinsic ligaments, ligaments between the carpal bones, and extrinsic ligaments, which cross the radiocarpal or ulnocarpal joint (Figure 1).

Figure 1, The intrinsic and extrinsic ligaments.



Palmar (intrinsic)		Palmar (extrinsic)		Dorsal (extrinsic)	
Scapholunate	SL	**Radiocarpal**		Radiotriquetral	Rtq
Lunotriquetral	LT	Radioscaphoid	RS	*(dorsal radiocarpal)*	*DRC*
Trapezium-trapezoid	TT	Radioscaphocapitate	RSC		
Capitotrapeziod	CT	Long radiolunate	LRL	Dorsal intercarpal *	DIC
Capitohamate	CH	Short radiolunate	SRL	*(scaphotriquetral)*	*Stq*
Scaphotrapezium-trapezoid	STT	**Ulnocarpal**			
Scaphocapitate	SC	Ulnolunate	UL		
Triquetrocapitate	TC	Ulnocapitate	UC		
Triquetrohamate	TH	Ulnotriquetral	UT		

* While it does not cross the radio/ulnocarpal joint, and therefore is in fact an intrinsic ligament, the DIC can be thought of as an extrinsic ligament, as it crosses multiple carpal bones.

2.4 The scapholunate interosseous ligament

The scapholunate (interosseous) ligament is c-shaped and can be subdivided in three regions: dorsal, palmar and proximal.[10,11] The dorsal region is considered the thickest part and consists predominantly of collagen fibers. The palmar region is thinner and consists of collagen, looser connective tissue and contains the greatest number of mechanoreceptors.[12] The dorsal region has a tensile strength twice the strength of the palmar region.[13] The proximal region consists of fibrocartilage and is not vascularized. Due to the histological and anatomical differences between the regions of the scapholunate ligament, there has been hypothesized that the regions have different functions.[13] As the dorsal region is the strongest, it might be most important in preventing dissociation between the scaphoid and lunate while the palmar region is predominantly involved in maintaining rotational stability.[13]

2.5 Stability of the scapholunate joint

Historically, the stability of the scapholunate interval was attributed solely to the scapholunate interosseous ligament and bone morphology.[14] However, more recent research highlighted the importance of additional structures like muscles, nerves (proprioceptive information) and other wrist ligaments.

Secondary stabilizers

Sequentially dividing surrounding ligaments like the radioscapho-capitate ligament (RSC), the Scaphotrapeziumtrapezoid ligament (STT) and the dorsal intercarpal ligament (DIC) showed significant attribution to the maintenance of normal scapholunate kinematics.[15–19] Therefore, these ligaments are often referred to as secondary stabilizers.

Morphology of the bones

Due to the articular surface (inclination and palmar tilt) of the radius, it fulfills a role in the dynamic stability of the joint allowing translation and rotation of the lunate and scaphoid.[20]

Muscle tendons

Besides the ligamentous stabilizers and the morphology of the bones, studies suggested the importance of muscle tendons and its pulleys like the m. flexor carpi radialis in stabilizing the interval by inducing supination to the scaphoid and pronation to the triquetrum.[21] Furthermore, when there is an abnormal tension of the dorsal and palmar fibers of the scapholunate ligaments, proprioception causes an automatic response via the cortex with tension of the extrinsic muscles (ECRB and ECRL, FCR, FCU and ECU).[21–24] This response exists to limit the harmful dynamics between the lunate and scaphoid, as well as to prevent the tearing of the scapholunate ligament.[25]

Proprioceptive information

The SLIL is predominantly innervated by the anterior interosseous nerve and terminal branches of the posterior interosseous nerve.[22] Following SLIL laceration, reduced sensory action potentials are detected compared to an intact ligament.[26] Furthermore, significant alterations of the wrist proprioceptive reflexes have been observed after posterior interosseous nerve anesthetics.[27] These studies suggested ligamentous and neurological injuries affect the neuromuscular control and play a role in the stability of the wrist.[22,26,27]

In conclusion, the stability of the scapholunate interval is provided by the carpal ligaments (primary and secondary stabilizers), the morphology of the bones, muscles and its tendon crossings and proprioceptive innervation.[8,22,28] Due to all combined and independent interactions, injuries to the scapholunate interval are considered complex.[29]

3.0 Scapholunate joint injuries

3.1 Etiology and terminology

A scapholunate joint injury can arise from a fall onto an outstretched hand. Just as the anterior cruciate ligament is considered a primary stabilizer of the knee, the SLIL is considered the primary stabilizer of the wrist joint.[30]

Incomplete or partial SLIL lesions lack a clear correlation with symptoms or progression into osteoarthritis. Complete SLIL injuries with injury to its secondary stabilizers are the most frequent cause of wrist instability. In literature, this condition is known as ‘scapholunate dissociation’ or ‘scapholunate instability’. However, even though these terms are sometimes used interchangeably, dissociation (misaligned) does not always mean the wrist is unstable.

Carpal malalignment or dissociation can be asymptomatic, therefore addressing changes in carpal alignment during motion and weight bearing solely through biomechanics is incomplete. Instability is defined as a symptomatic wrist dysfunction, that cannot bear loads without giving way, lacks normal kinematics during motion and cannot be reduced by unloading the joint.[31]

SL joint injuries can be described as a spectrum of injuries and is often subdivided in four stages: predynamic instability, dynamic instability, static scapholunate dissociation and Scapholunate Advanced Collaps (SLAC).[32] In predynamic instability patients can present with wrist pain but radiographs show no malalignment. In dynamic instability, abnormalities of carpal alignment can only be seen on clenched wrist radiographs or during fluoroscopy. If malalignment is

seen on plain, static radiographs, it is called static scapholunate dissociation. When there is evidence for displacement of the scaphoid and osteoarthritis, it is called Scapholunate Advanced Collaps or SLAC.[7]

Furthermore, carpal instability can be subdivided in carpal instability dissociative (CID), or carpal instability non dissociative (CIND). CID is characterized by dissociation between bones in the same carpal row. In CIND no dissociation in the proximal carpal row is observed but malalignment exists between the proximal row with the distal forearm or distal carpal row.

As 'scapholunate instability' or 'scapholunate dissociation' does not encompass the full spectrum of scapholunate injuries, this thesis will use the term 'scapholunate dysfunction'.

4.0 Diagnostics

4.1 Examination and radiology

Patients may present with swelling and pain at the dorsal side of the wrist in the area of the SL joint.[33] Physical examination includes provocative test like the scaphoid shift test, also known as the Watson test.[34,35] During this test the patient's wrist needs to be relaxed. The wrist is moved from ulnar deviation and slight extension to radial deviation and slight flexion while holding pressure with the examiners thumb on the scaphoid.[35] During this motion the scaphoid rotates while the examiner's thumb creates a subluxation stress, causing the scaphoid to shift. If tension of the thumb is relieved and the scaphoid 'clunks' back, there is some degree of laxity. The test is positive if there is asymmetry between the affected and unaffected side.

Static and dynamic radiographs of both wrists can be made to reveal disruption in Gilula lines, an increase in scapholunate angle, diastasis between the scaphoid and lunate, over projection of the scaphoid or osteoarthritis. If plain radiographs are inconclusive, cineradiography, computed tomography (CT) and magnetic resonance imaging (MRI) may confirm suspected scapholunate joint injuries. Furthermore, 4D-CT can be performed to assess the wrist in a dynamic way.

If combined clinical and radiological examinations is inconclusive, some surgeons offer diagnostic arthroscopy.

4.2 Arthroscopy

Since the first wrist arthroscopy performed on human specimen in 1932, arthroscopy gained popularity and is currently considered gold standard for the diagnosis of scapholunate pathology.[36–38] Other clinicians point to the fact that the usage of arthroscopy in the evaluation of SLIL pathology might contribute to greater use of diagnostic surgery with unclear potential for benefit.[39] De Smet *et al.* noted that arthroscopy has the ability to identify previously unnoticed lesions.[40] The unclear clinical significance of these newfound lesions raises questions about appropriate indications for arthroscopy, and making more knowledge of its limitations necessary.[40]

Two widely used classifications to describe scapholunate pathology arthroscopically are the Geissler classification and the European Wrist Arthroscopy Society group (EWAS) classification.

Table 1, Geissler arthroscopic classification.

Grade I	Attenuation/hemorrhage of interosseous ligament as seen from the radiocarpal joint. No incongruency of carpal alignment in the midcarpal space.
Grade II	Attenuation/hemorrhage of interosseous ligament as seen from the radiocarpal joint. Incongruency/step-off as seen from midcarpal space. A slight gap (less than width of a probe) between carpals may be present.
Grade III	Incongruency/step-off of carpal alignment is seen in both the radiocarpal and midcarpal spaces. The probe may be passed through the gap between carpals.
Grade IV	Incongruency/step-off of carpal alignment is seen in both the radiocarpal and midcarpal spaces. Gross instability with manipulation is noted. A 2.7-mm arthroscope may be passed through the gap between carpals.

Table 2, European Wrist Arthroscopy Society group (EWAS) classification.

Stage I	No passage of the probe in SL space, but synovitis.
Stage IIA	Volar passage in the SL space without widening
Stage IIB	Dorsal passage in the SL space without widening
Stage IIC	Complete passage in the SL space without widening
Stage IIIA	Volar partial widening at dynamic instability test from MC joint (volar instability)
Stage IIIB	Dorsal partial widening at dynamic instability test from MC joint (dorsal instability)
Stage IIIC	Complete widening of the space at dynamic test
Stage IV	Gap with passage of the arthroscope from MC to RC joint

5.0 Treatment

5.1 Directing treatment

While there are few studies concerning non-surgical treatments, numerous surgical procedures and modifications have been documented.[41] There is no consensus on the most appropriate techniques and treatment recommendations. Most performed techniques include direct repair, capsulodesis and tenodesis techniques of which some are summarized in Table 1.[42–45] Arthrodesis and carpectomy is beyond the scope of this thesis.

Table 1, Reported surgical procedures and modifications for scapholunate interosseous ligament injuries.

Direct repair	Capsulodesis	Tenodesis
• Bone anchor	• Blatt capsulodesis	• Brunelli tenodesis
	• Viegas capsulodesis	• van den Abbeele tenodesis
	• Mayo capsulodesis	• 3-ligament tenodesis
	• Berger capsulodesis	• SLAM technique
		• 360° tenodesis
		• ECRL tenodesis
		• 4-bone tendon weave
		• Scapholunotriquetral tenodesis

All procedures aim to restore scapholunate ligament continuity and preventing the scaphoid from flexion/pronation and thereby normalize carpal biomechanics preventing the onset of osteoarthritis. In acute phases (< 3 weeks) direct repair of the SLIL might be possible.[46] Subacute/chronic injuries (≥ 3 weeks) show inferior results.[46,47] Staging the degree of the injury and the stage of dysfunction is important in defining the operative treatment. To guide treatment recommendations an algorithm for the recommended treatment was proposed based on six questions[48]

1. Is the SLIL injury partial or complete?
2. Does the SLIL have sufficient tissue to be repaired?
3. Is the scaphoid posture normal?
4. Is the lunate posture normal?
5. Is the carpal malalignment reducible?
6. Is the cartilage on the radiocarpal and midcarpal surfaces normal?

Still, guiding patients in making treatment decisions is considered difficult and is accompanied with a wide surgeon-to-surgeon variation. To achieve consensus, more knowledge is needed about the factors that influence this variation in care.

5.2 Post operative treatment

The literature regarding the post-operative treatment (immobilization and start of rehabilitation) of commonly used surgical techniques is very limited. Varied durations of immobilization spanning from 2 weeks to 8 weeks are reported.[48–50]

To improve rehabilitation after SL surgery more information about immobilization and rehabilitation might be valuable. Prolonged immobilization could alter the mechanical properties of ligament- or tendon grafts, which might result in a stiff wrist and a reduction in range of motion. On the contrary, short immobilization and early initiation of rehabilitation might possibly harm the reconstruction.

If shorter immobilization and early start of exercises does not lead to more complications or worse outcomes, it might potentially yield more patient comfort, faster return to activities and a reduction of costs.

5.2 Distal radius fractures

Since SLIL pathology and distal radius fractures both primarily arise from a fall on outstretched arm, these injuries can coincide. Previous research report that concomitant ligament injuries can occur up to 13-50%.[51–53] Currently there is a lack of agreement regarding the need for immediate treatment for these concomitant injuries. More information is needed to determine if concomitant ligament injuries influence patient related outcome in patients treated operatively for a distal radius fracture.

6.0 Aims of this thesis

In general, the aim of this thesis is to investigate biomechanical properties after common surgical interventions, the reliability of arthroscopic evaluation of the wrist, to study factors associated with treatment recommendations, the quality of online patient information and rehabilitation regimens for scapholunate joint pathology. Furthermore, this thesis will study ligament injuries concomitant to distal radius fractures, and their effect on patient reported outcome.

This is specified in the following aims:

1. Evaluate biomechanical properties after capsulodesis and tenodesis for SLIL dysfunction.
2. To investigate the role of diagnostic arthroscopy, the reliability, and what factors are associated with treatment recommendations.
3. To assess the quality of online patient information on SLIL pathology.
4. To define current post-operative treatment regimens for SLIL pathology.
5. To obtain an evidence-based rehabilitation regimen after a 3-Ligament Tenodesis.
6. To study patient related outcome after operatively treated distal radius fractures with suspected concomitant ligamentous pathology.

7.0 Outline of this thesis

Part I Exploring wrist biomechanics after common scapholunate ligament reconstructions.

Within this part, **Chapter 2** and **Chapter 3** will explore biomechanical aspects of the wrist after a dorsal capsulodesis according to Mayo and after a 3-Ligament Tenodesis (3-LT).

Part II Diagnostics and treatment recommendations for scapholunate ligament injuries.

To understand surgeons' treatment recommendations, **Chapter 4** and **Chapter 5** focus on arthroscopic grading, factors influencing surgical decisions, and the reliability of arthroscopic grading for suspected SLIL pathology. Additionally, **Chapter 6** will evaluate the quality, readability and underlaying tone of online patient information.

Part III Treatment of scapholunate ligament injuries.

Chapter 7 is dedicated to outline the currently described immobilization regimens after reconstructive procedures for Scapholunate ligament injuries. In **Chapter 8** we study patients treated following an early active or late active motion protocol after 3LT. Furthermore, we study patient related outcome after operatively treated distal radius fractures with suspected concomitant ligamentous pathology (**Chapter 9**).

Part IV General discussion, future perspectives, and summary.

Finally, in **Chapter 10** the results from all chapters will be discussed and future perspectives will be described. In **Chapter 11** the results will be summarized.

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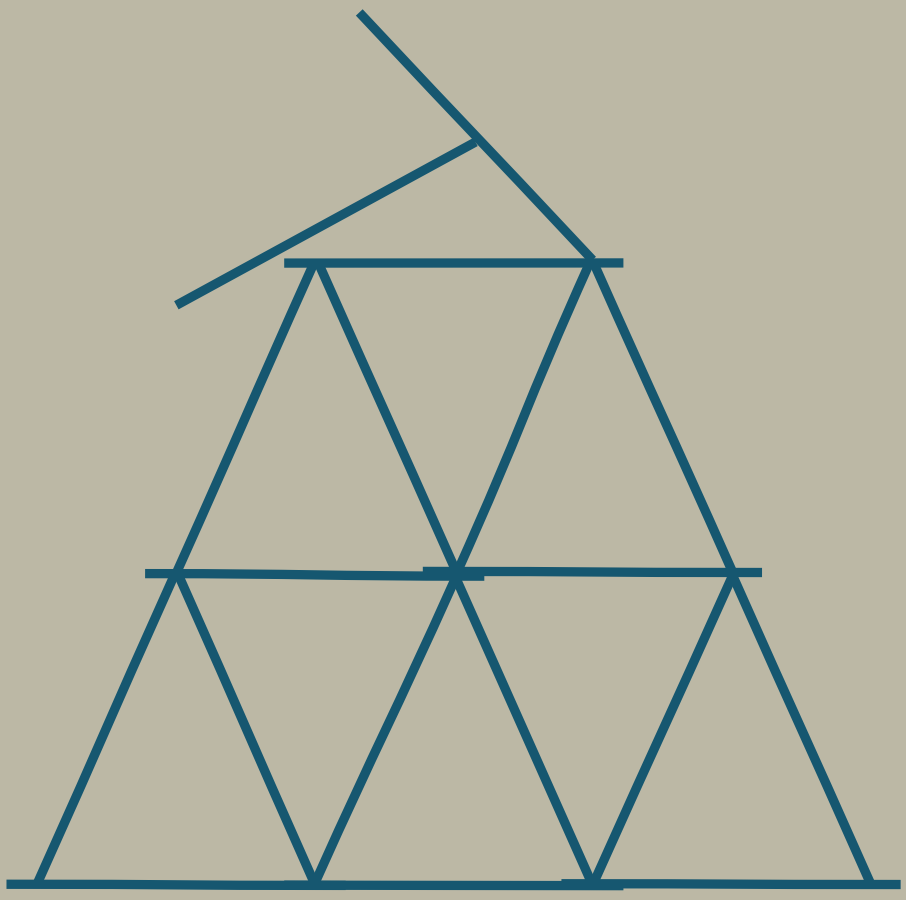
Part I

Exploring wrist biomechanics after common scapholunate ligament reconstructions.

2 Assessment of flexion elongation relation and type of failure after capsulodesis.



Journal of Wrist Surgery, 2020;9:382-387
Daniel Bakker
Gerald A. Kraan
Nina M. C. Mathijssen
Joost W. Colaris
Gert-Jan Kleinrensink

Abstract

Background

Injury of the scapholunate interosseous ligament is the most frequently diagnosed cause of carpal instability and can be treated with a Mayo capsulodesis procedure. During this procedure a radially based flap of the dorsal radiocarpal complex is attached to the lunate. The procedure attempts to reduce flexion of the scaphoid and restore the scapholunate relationship by crossing the scapholunate interval. To obtain a better understanding of the biomechanical properties and possibly improve the post-operative rehabilitation process, a better understanding of the reconstructions biomechanics is needed.

Methods

Ten dorsal intercarpal ligament capsulodesis were performed on embalmed wrists to assess the flexion elongation relation at the dorsal intercarpal reconstruction, the dorsal intercarpal complex and the type of failure during flexion of the wrist.

Results

The mean elongation of the dorsal intercarpal reconstruction at 70-degree flexion was 0.8 mm. During flexion, the dorsal intercarpal reconstruction showed no ligament tears or failure of the bone anchor. The mean elongation of the dorsal intercarpal complex was 3.9 mm at 70 degrees. During subsequent repeated flexion, four sutures to connect the dorsal intercarpal complex to the surrounding tissue loosened between 55 and 60 degrees.

Conclusions

These findings suggest that capsulodesis can safely withstand flexion of the wrist until 50 degrees.

Clinical relevance

Clinicians should consider the opportunity to start early with controlled active motion.

Introduction

Injuries of the scapholunate interosseous ligament (SLIL) are the most frequently diagnosed cause of carpal instability.[1] Usually, this injury is the result of a fall onto an outstretched hand with the wrist in extension, ulnar deviation, and intercarpal supination.[2] The SLIL ruptures can result in painful carpal instability and progression into a predictable pattern of degenerative osteoarthritis better known as scapholunate advanced collapse (SLAC).[3] To treat pain and instability and prevent progression into a SLAC wrist, numerous surgical methods have been proposed.[4–6] In 1987, Blatt introduced a method using a part of the dorsal intercarpal capsule to attach on the radius.[7] This capsulodesis method has been modified by attaching the dorsal intercarpal reconstruction (DIR) at the surface of the lunate, also known as the Mayo capsulodesis.[8,9] The capsulodesis attempts to limit scaphoid flexion and restore the relationship between the scaphoid and lunate by attaching the distal pole to the lunate by a dorsal capsule flap.

Previous studies showed improvement in pain and stability after capsulodesis and 58% patient's satisfaction rate over 5 years follow-up.[10,11] Nevertheless, disadvantages of capsulodesis are postoperative lack of wrist flexion, minimal improvement in radiographic parameters, and the inability to preserve radiographic improvement at long-term follow-up.[10,12]

Patients are generally immobilized in cast to protect the capsulodesis, while immobilization of the wrist results in stiffness and atrophy. However, if movement of the wrist does not damage the surgical reconstruction, early active motion after surgery might be possible.

Therefore, the surgical reconstruction needs to be studied. The aim of this study on anatomic specimens was to determine the palmar flexion elongation relation of the DIR and the dorsal intercarpal complex (DIC), and, to study the ability of the capsulodesis to withstand flexion without failing.

Methods

Ten wrists were embalmed according to the AnubiFiX (AnubiFiX, Rotterdam, The Netherlands) method. This method preserves tissue and joint flexibility and can therefore be a representation of normal biomechanics.[13,14] Three female and seven male wrists with a mean age of 86.8 years (range: 72–100) were used, of which three were left and seven right.

All specimens were visually examined by an orthopaedic surgeon for evidence of pre-existing lesions or prior surgery of the wrist. All arms were disarticulated at the elbow joint. Ten dorsal intercarpal ligament capsulodesis procedures were performed by one orthopaedic surgeon according to the same surgical protocol.

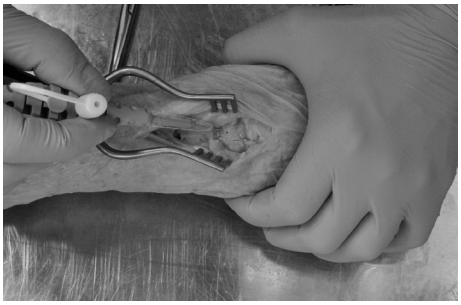
Surgical Technique

During the entire surgical procedure, the wrist was placed in neutral position. A longitudinal incision of 4 cm starting 1 cm ulnar of Lister's tubercle was made. The extensor retinaculum was opened following the course of the third extensor compartment. Then the fourth extensor compartment was opened (▶Fig. 1A). The carpal bones were exposed following the Berger et al's approach[8] the incision started at the scaphotrapeziotrapezoid joint and moved ulnar until the dorsal ridge of the triquetrum. At the triquetrum, the incision took a proximal oblique course following the fibers of the dorsal radiocarpal ligament until the center of the lunate fossa. The radially based flap of capsule was tangentially elevated and released from the dorsal surfaces of the lunate and proximal scaphoid (▶Fig. 1B). The SLIL was identified and sectioned (▶Fig. 1C). A JuggerKnot Soft Suture Anchor (Biomet, Inc., Warsaw, IN) was inserted into the lunate (▶Fig. 1D). A radially based 0.5 cm wide flap of dorsal intercarpal ligament was developed from the elevated capsular flap (▶Fig. 1E). This 0.5 cm DIR was fixed with tension onto the lunate to reconstruct the SLIL ▶Fig. 1F). The remaining radially based flap of capsule was sutured with Vicryl absorbable sutures 3.0 over the DIR to restore the DIC (▶Fig. 1G and H).

Fig. 1 Surgical approach of the dorsal intercarpal ligament capsulodesis with a bone-anchor.

1a

1b



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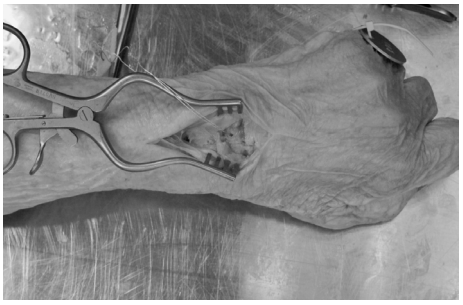

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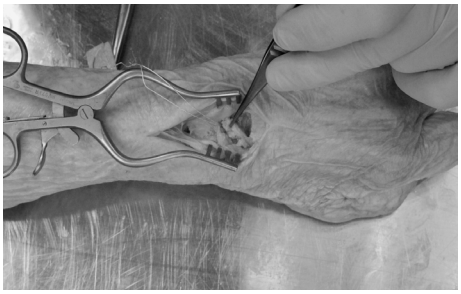

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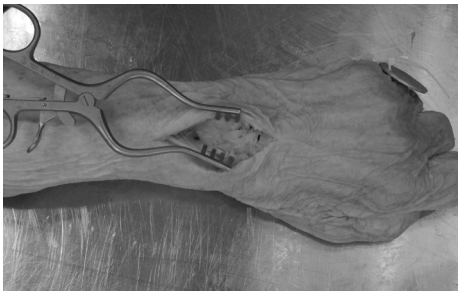

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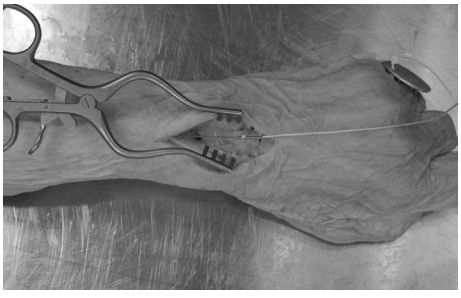


1j

(**A**) An incision of 1 cm ulnar from Lister's tubercle (*) was made. The extensor retinaculum was opened. (**B**) A radially based flap was created. The incision started at the scaphotrapeziotrapezoid joint (1) and moved ulnar until the dorsal ridge of the triquetrum (2). At the triquetrum, the incision took a proximal oblique course following the fibers of the dorsal radiocarpal ligament until the lunate fossa (3). (**C**) The scapholunate interosseous ligament was identified and sectioned. A JuggerKnot Soft Suture bone Anchor was used. (**D**) The bone anchor was inserted into the lunate. (**E**) From the radially based flap, a smaller flap (dorsal intercarpal reconstruction, DIR) was created. (**F**) The DIR was fixed onto the lunate using the bone anchor. (**G**) The bone anchor was sutured in the center of the overlaying radially based flap. (**H**) The remaining radially based flap connected to the surrounding tissue to restore the dorsal intercarpal complex (DIC). (**I**) For measuring the elongation of theDIR, the differential variable reluctance transducer (DVRT)-sensor was placed at the bone anchor in the lunate (1) and at the radial origin of the DIR (2). (**J**) For measuring the elongation of the dorsal intercarpal complex, the DVRT-sensor was placed at the bone anchor in the lunate (1) and Lister's tubercle (2).

Measurement Technique

Each forearm was mounted into a testing apparatus to simulate palmar flexion (▶Fig. 2). For the assessment of elongation, a differential variable reluctance transducer (DVRT) (LORD Sensing, Williston, VT) was used. A DVRT sensor measures linear displacement between two sites. To record elongation of the DIR, the DVRT was mounted at the location where the bone anchor was fixed at the lunate and the radial origin of the DIR (▶Fig. 1I). To quantify the elongation of the DIC, the transducer was placed at the location where the JuggerKnot was fixed onto the lunate and Lister's tubercle (▶Fig. 1J). A Caperlan wire (Solognac-Caperlan, Cestas, France) was sutured around the third metacarpal, and through two fixed pulleys attached to a universal testing machine (Testometric Co, Rochdale, United Kingdom). The machine moved vertically at a speed of 5.0 mm/s, resulting in palmar flexion of the wrist. Data extraction started when the universal testing machine reached a 0.5 N preload. To quantify palmar flexion, a digital goniometer was attached at the dorsal aspect of the hand. To assess the elongation of the DIR, ten wrists were tested five times from neutral position to 70-degree flexion. After testing the DIR, the DIC was tested. The test stopped if either the DIR or DIC failed, or the suture or the anchor was pulled out. Data was represented as the mean and standard deviation (SD) in a flexion elongation curve.

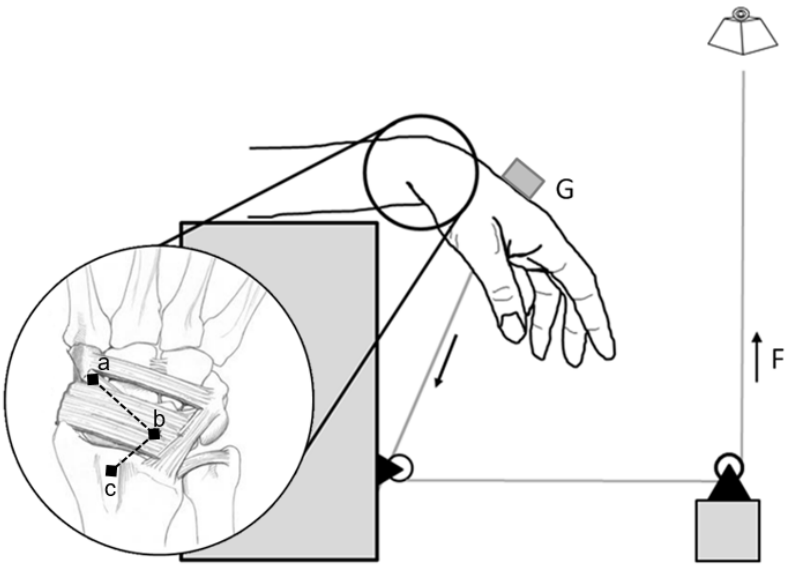


Figure 2. Schematic overview of testing apparatus. The universal testing machine is moving vertically (F), resulting in palmar flexion of the wrist. The DVRT sensor was placed at the radial side of the dorsal intercarpal reconstruction (DIR) (a) and at the bone anchor (b) to measure the elongation of the DIR, and from the bone anchor (b) to Listers tubercle (c) to measure the elongation of the dorsal intercarpal complex (DIC). A digital goniometer (G) at the dorsal aspect of the hand was used to quantify the palmar flexion.

Results

No pre-existing lesions or evidence for prior wrist surgery were found on the anatomic specimen. The mean elongation of the DIR at 70-degree palmar flexion was 0.8 mm (SD: 0.6) (▶Fig. 3). The mean elongation of the DIC was 0.03 mm (SD: 0.1) at 5 degrees and 3.9 mm (SD: 1.7) at 70 degrees (▶Fig. 4). Visually, the DIR showed no bone anchor failure during the repeated flexion tests until 70 degrees. In four arms sutures to connect the proximal DIC to the surrounding tissue loosened at 55- and 60-degree palmar flexion.

Figure 3. Linear elongation to palmar flexion on the dorsal intercarpal reconstruction.

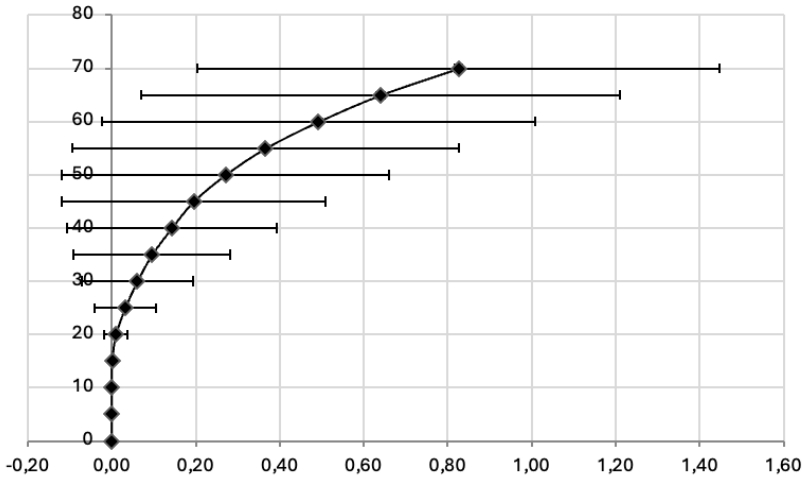
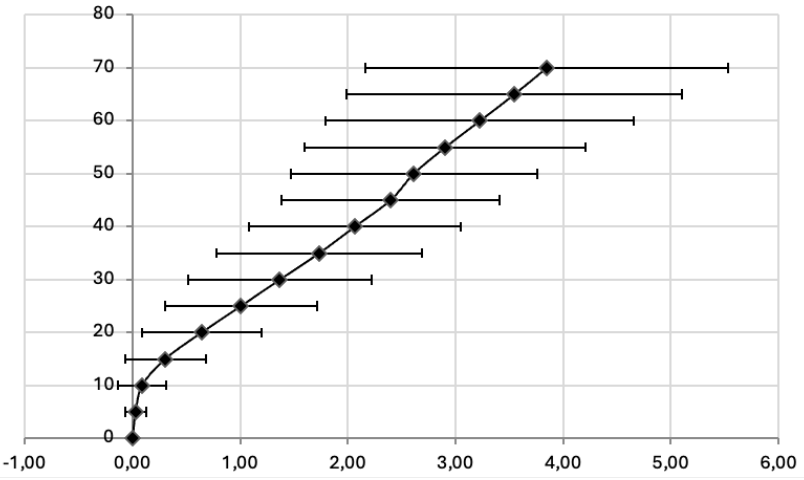


Figure 4. Linear elongation to palmar flexion on the dorsal intercarpal complex.



Discussion

Symptomatic scapholunate instability can surgically be treated by a capsulodesis. In this study, the capsulodesis reconstruction was tested during 0- to 70-degree palmar flexion without failing of the bone anchor. The DIR and DIC showed minimal elongation during early flexion. Sutures to connect the proximal side of the DIC to the surrounding tissue loosened at 55 and 60 degrees. These results might indicate controlled early active motion is safe until 50-degree palmar flexion.

The SLIL is not the only ligament involved in stabilizing the scapholunate interval. At the volar side of the wrist, the palmar radiocarpal ligament, radioscaphocapitate ligament, and the scaphotrapeziotrapezoid ligament contribute to stability. At the dorsal side, the dorsal intercarpal ligament and the dorsal radiocarpal ligament stabilize the interval.

Previous biomechanical studies categorized the wrist ligaments in primary and secondary stabilizers.[15–17] Only after sectioning the SLIL, significant changes in movement of the lunate and scaphoid were observed. These results suggested the SLIL ligament is the primary stabilizer. When carpal instability occurs in patients, more stabilizers might be torn. To limit the effect of multiple variables, this study observed reconstruction elongation with a sectioned SLIL only.

Capsulodesis reconstructions resulted in significant reduction in pain and increase in grip strength.[18,19] However, flexion of the wrist can be reduced significantly to 45 degrees.[10,11,20] Although improvements in scapholunate angle and scapholunate gap were found in short-term follow-up, the alignment seems not to be maintained at longer follow-up.[11] Still, most patients treated with capsulodesis were asymptomatic and none needed further treatment.

To protect the capsulodesis, patients are generally immobilized allowing the tissues to heal. However, immobilization of a joint results in stiffness and atrophy. The balance between protection and prevention of motion loss is considered difficult. The results of this study indicate capsulodesis create a reconstruction that can withstand 50-degree palmar flexion with minimal amounts of elongation during early flexion. Furthermore, no failure of the bone anchor was seen. In four arms, the suture knots were loosening at the proximal side of the DIC between 55- and 60-degree palmar flexion. At the time the suture loosening occurred, the mean DIC elongation of the four wrists was 3.8 mm. The mean DIC elongation of all wrists was 3.9 mm. This difference is presumably caused by differences in soft tissue stiffness of the used upper limbs, indicating the wrists in which loosening occurred was less stiff. No tissue ruptures or suture tears were observed. This observation implies extra attention is needed in suturing the proximal side of the DIC.

This study has several limitations. First, only palmar flexion was tested. Although postoperative palmar flexion is reduced most, it would be thorough to examine extension, ulnar and radial deviation as well.

Second, this study used a limited number of embalmed upper limbs of older people and a limited number of tests on the same upper limb. Because embalming can cause shrinkage of anatomical structures, the measurements might have influenced the size and quality of the ligaments. Furthermore, flexion greater than 45 degrees might have caused distraction of the wrist and stretch the DIC repair. This might have affected the results. Although the absolute displacements and angulations may include uncertainties, the trends of the measurements are helpful because the results have always been interpreted in relation to displacement in the same structure. This type of surgery leads to stiffness and scarring of patient wrists capsule, which influences the range of motion and provides more stability. Because we used embalmed upper limbs, this process could not occur and may have influenced our results. The nearest to the human in vivo situation would be to perform measurements on unembalmed human bodies. Because we used human bodies of older age, we had to cope with inferior soft tissue and absence of scar tissue. This suggests that the capsulodesis, which is normally performed on younger patients, might withstand more flexion.

Third, this study focused on one surgical intervention, while several techniques are reported for injuries of the SLIL, including tenodesis. The Brunelli tenodesis and its modifications attempt to correct scaphoid dissociation and flexion by tunneling a tendon graft through the scaphoid and connecting it to the lunate.[4,5] Like the capsulodesis, tenodesis is associated with a decrease in postoperative range of motion and grip strength.[5] It would be valuable to know more about the biomechanics to improve postoperative results.

Conclusions

Despite the limitations, this study showed that during early palmar flexion the elongation of the reconstruction is minimal, and the bone anchor showed no failure. The capsulodesis creates a reconstruction which can withstand 50° palmar flexion with minimal amounts of elongation. This supports the hypothesis that a controlled early rehabilitation might be possible.

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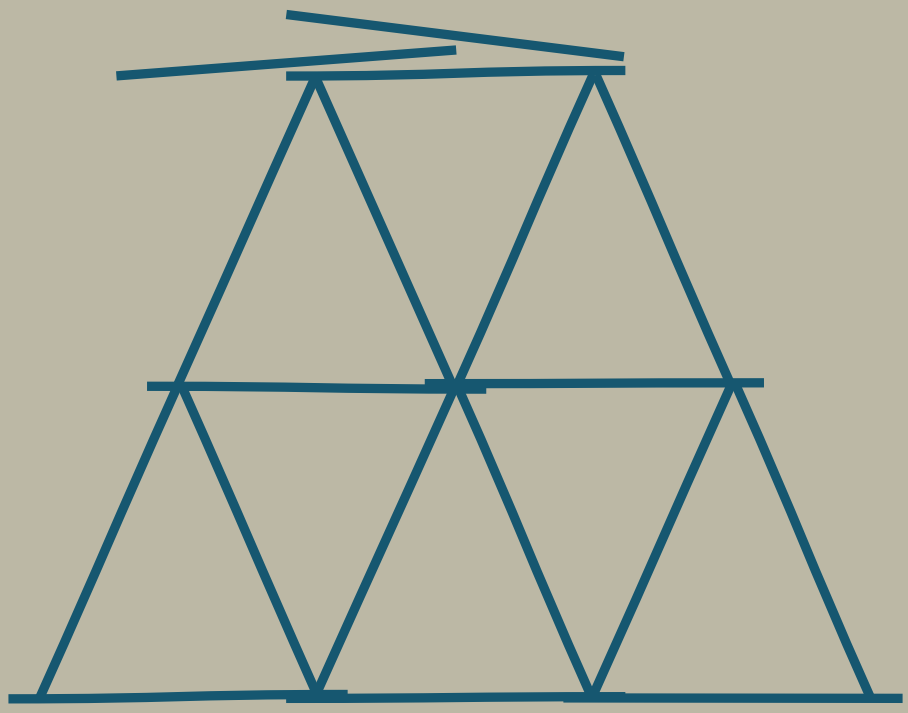
3 Flexor Carpi Radialis and Dorsal Intercarpal Complex Elongation After 3 Ligament Tenodesis.



Journal of Hand Surgery, European volume (SUBMITTED)

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Gerald A. Kraan

Abstract

To improve the surgical procedure and rehabilitation after surgery, a better understanding of the biomechanical properties of the three ligament tenodesis (3LT) procedure is necessary. This study examined elongation in relation to flexion, and type of failure after 3LT using ten anatomic specimens, each wrist undergoing five tests. At 80° flexion mean elongation of the flexor carpi radialis (FCR) tendon slip was 0.96 ± 0.38 mm. Mean elongation of the Dorsal Intercarpal Complex (DIC) was 3.75 ± 0.91 mm. at 80° flexion. Relative elongation at the FCR tendon slip was 4.1% and 33.4% at the DIC. In two tests (4%), sutures loosened at the proximal side of the DIC after 30° flexion. Ruptures of the radiotriquetral ligament, pull-outs of the bone anchor or FCR tendon ruptures were not observed. This experiment suggests that following 3LT, the most elongation occurs at the DIC. Since instances of failure were noted at the proximal aspect of the DIC, if early active motion protocols are used, it is recommended to initiate wrist flexion with a limitation to 30° wrist flexion.

Introduction

Injuries to the scapholunate joint are the most important cause of carpal instability.[1] More recent, the concept of a stabilizing complex was introduced.[2] This scapholunate complex consists of the SLIL, the scaphotrapezio-trapezoid ligament, the radiolunate ligament, the radioscaphoid ligament, the dorsal intercarpal ligament and the flexor carpi radialis, extensor carpi radialis longus and flexor carpi ulnaris muscles. Injuries of the scapholunate complex can lead to alterations of articular dynamics which can result in pain, decreased grip strength and disability. Moreover, if left untreated, it may lead to osteoarthritis.[3]

Numerous surgical procedures for the treatment of instability have been proposed including direct repair, capsulodesis, tendon graft procedures and arthroscopic repair. The aim of tendon grafts is to reduce flexion of the scaphoid and correcting dissociation between the scaphoid and lunate. The use of the Flexor Carpi Radialis tendon (FCR) was first described by Brunelli and has been modified by van den Abbeele and Garcia-Elias.[4–6] Using the three ligament tenodesis (3LT) for management of scapholunate injuries is performed and advocated by multiple authors.[7,8]

The 3LT procedure is associated with an improvement of post-operative Disabilities of the Arm, Shoulder and Hand (DASH) scores, reduction of pain and reduction of SL-gap.[9,10] However, disadvantages are a decrease in wrist motion, especially flexion, and grip strength.[5]

To improve the surgical procedure and the rehabilitation after surgery, a better understanding of the biomechanical properties after a 3LT procedure is necessary. For this reason, it would be valuable to understand which parts of the reconstruction are involved most in limiting flexion.

Second, according to the original case series of the 3LT technique, a six-week post-operative immobilizing cast is indicated to protect the reconstruction.[5] As a side effect, immobilization results in loss of mobility, stiffness, atrophy and a longer rehabilitation period. If wrist movement does not appear to damage the surgical reconstruction, a faster start of the rehabilitation after surgery might be possible.

The objective of this anatomical specimen-based study is to evaluate the absolute and relative elongation of the FCR tendon slip and the dorsal intercarpal complex (DIC) during flexion. Secondary, this study aims to assess the reconstructions capacity to endure maximal flexion without failure. In the event of failure, we aim to objectify the nature of the failure.

Methods

Ten specimens were disarticulated at the shoulder joint and embalmed according to the AnubiFiX method (AnubiFiX, Rotterdam, The Netherlands). This method is used to preserve tissue and joint flexibility.[11,12] After disarticulation, all wrists were visually examined by a wrist surgeon for evidence of prior surgery and pathological changes. 3LT was performed by the same surgeon according to the same surgical protocol.

Surgical technique

Following Berger and Bishops approach, an incision was made starting 1 cm. ulnar of Lister's tubercle.[13] The underlying 3rd and 4th extensor loge was opened. To open the overlaying capsule an incision was made starting at the radial styloid, which moved ulnar until the center of the lunate fossa. From the lunate fossa the incision moved in a distal direction following the fibers of the dorsal radiocarpal ligament until the insertion on the triquetrum. A second incision was made at the level of the scaphotrapezio-trapezoid joint and progressed in ulnar direction, splitting the DIC until its insertion on the triquetrum connecting the two incisions. The radially based capsular flap was elevated from the carpal bones. The SLIL was identified and transected entirely. At the volar side of the wrist, a slip was split from the FCR tendon and pulled dorsally through a drilled hole in the scaphoid. The FCR-tendon slip was fixed on the lunate using a bone anchor. The FCR-tendon slip was pulled through the radiotriquetral ligament (RTq), and sutured on itself. The radially based DIC flap was sutured to the surrounding tissue to restore the dorsal capsule.

Measurement technique

Each specimen was solidly fixed into a testing apparatus (Testometric Co, Rochdale, United Kingdom). A wire was sutured around the third metacarpal bone, guided through two fixed pulleys and attached to the vertically moving apparatus with a speed of 5.0 mm/s resulting in wrist flexion (Appendix 1). A digital goniometer was used for measuring flexion. Each specimen underwent five tests, ranging from neutral position to a maximum of 85°. Data extraction started when a pre-load of 0.5 Newton was reached.

To assess elongation, a differential variable reluctance transducer (DVRT) (Microstrain, Burlington, VT) was placed over two intervals (Figure 1). To assess the elongation of the FCR-tendon slip, the DVRT was positioned in the FCR tendon where the slip left the scaphoid tunnel and at the bone anchor site. After testing elongation of the FCR-tendon slip, the DIC was sutured to restore the capsule. To quantify the elongation of the DIC, a second interval was used. The transducer was placed at Lister's tubercle and at the site where the FCR-tendon slip was attached to the lunate. If the FCR-tendon slip or the DIC failed, the test was stopped.

Continuous variables were represented as mean and standard deviation. Failure was quantified through the count of observations and corresponding percentage of suture loosening, suture pull-outs, suture failures, bone anchor failures, FCR-tendon slip tears and ligament tears.

Results

No evidence for prior surgery or other significant pathology was observed. One of the anatomic specimens showed ossification at the SLIL during the surgical procedure. In all specimens the SLIL was intact. All wrists were tested five times resulting in 50 tests of the FCR-tendon slip and 50 of the DIC.

Mean elongation at the FCR-tendon slip was 0.96 ± 0.38 mm. at 80° flexion. At 80° flexion mean DIC elongation was 3.75 ± 0.91 mm. (Table 1). The mean starting lengths of the FCR-tendon slip and the DIC were 13.71 mm. and 13.04 mm. Maximum relative elongation at the FCR tendon slip was 4.1%. Maximum relative elongation at the DIC was 33.4%.

No rupture of the RTq ligament, failure of the FCR tendon slip or pull out from the bone anchor was observed. In two wrists (2/50, 4%), suture loosening was observed at the proximal side of the DIC. Loosening occurred at 30° and at 55° flexion. No DIC ligament tears were seen.

Table 1. Elongation and relative elongation of the FCR tendon slip and the DIC during wrist flexion.

	FCR-tendon slip		DIC	
Wrist flexion (°)	elongation (mm.)	Δ elongation (%)	elongation (mm.)	Δ elongation (%)
5	0.001 (± 0.001)	0	0.15 (± 0.17)	1.2
10	0.005 (± 0.01)	0	0.29 (± 0.22)	2.7
15	0.01 (± 0.02)	0	0.29 (± 0.30)	4.1
20	0.03 (± 0.04)	0.2	0.58 (± 0.28)	5.9
25	0.05 (± 0.06)	0.4	0.93 (± 0.46)	8.0
30	0.08 (± 0.09)	0.6	1.29 (± 0.52)	10.7
35	0.11 (± 0.11)	0.8	1.63 (± 0.58)	13.3
40	0.15 (± 0.13)	1.1	1.98 (± 0.66)	16.0
45	0.18 (± 0.15)	1.3	2.29 (± 0.72)	18.2
50	0.19 (± 0.16)	1.5	2.56 (± 0.77)	19.9
55	0.23 (± 0.17)	1.8	2.88 (± 0.84)	21.9
60	0.28 (± 0.20)	2.2	3.18 (± 0.91)	24.0
65	0.37 (± 0.24)	2.9	3.42 (± 1.03)	25.4
70	0.43 (± 0.29)	3.3	3.67 (± 1.14)	27.0
75	0.50 (± 0.36)	3.3	3.58 (± 1.17)	27.4
80	0.96 (± 0.38)	4.1	3.75 (± 0.91)	32.0
85	NA	NA	4.25 (± 1.21)	33.4

Discussion

Various studies explored the biomechanical properties of the SLIL. The biomechanical properties of the 3LT procedure are, despite its use, relatively unknown. Examination of the relation between wrist flexion and (relative) elongation and identification of failure during flexion might be valuable to improve the surgical treatment and faster recovery. This study found that during flexion more relative elongation is observed at the DIC compared to the FCR-tendon slip. Furthermore, loosening of sutures was observed at the proximal side of the DIC. No failure of the tendon graft, RTq ligament or bone anchor occurred.

Our study found that elongation at the DIC was 3.75 ± 0.91 mm. during 80° flexion. This is in line with results from a prior biomechanical study, which reported an elongation of 3.9 ± 1.7 mm. after capsulodesis.[14] Elongation at the FCR-tendon slip was 0.96 ± 0.38 mm, which was lower in comparison to the DIC. Similarly, more relative elongation was found in the DIC compared to the FCR-tendon slip. This difference might be caused by collinearity of the direction of the force and the interval measured, relative laxity of the DIC or the possibly that the DIC channels most forces during wrist flexion. Recent studies reported the existence of ligamentous attachment from the SLIL to the DIC and sectioning leaded to instability.[15,16] This could suggest the DIC and its attachments have an important role in stabilization of the scapholunate interval after reconstruction.

The observation that loosening of sutures can occur at the proximal side of the DIC are consistent with a previous study concerning the biomechanics of capsulodesis, which found loosening of the proximal DIC sutures after 50° flexion.[14] Care must be taken in suturing the proximal DIC.

Previous studies reported attention is needed during the procedure avoiding complications like ruptures of the RTq ligament, pull-outs of the bone anchor or FCR tendon ruptures.[5,17] None of these complications were observed in our study. As relative elongation at the FCR tendon slip was only 4.1%, tensioning of the RTq might not be significant. However, this study only tested the 3LT with the same loading, more weight might alter elongation of the FCR tendon slip.

Nowadays, rehabilitation starts following an immobilization period of 6 to 8 weeks. If future research addresses early active motion, this study suggest initiating wrist flexion with a limitation to 30° wrist flexion as suture loosening occurred after 30° flexion.

This study has several limitations. First, all tests were performed on a limited number of wrists. Previous studies on SL pathology using anatomic specimen have involved 5 to 12 wrists.[18–20] We believe testing 10 wrists, five times each, would be

sufficient to make an adequate estimation of the flexion-elongation relation after 3LT. Second, like in all biomechanical studies, using postmortem human subjects concern the study conditions are not comparable to the in vivo reality. Especially in wrist surgery where scar tissue formation is thought to be an important aspect of the treatment, our model lacks this factor. Third, in this study we only transected the SLIL. Previous studies reported stabilization of the wrist is the result of primary and secondary stabilizers. To limit the effect of more than one variable, we only transected the SLIL. Fourth, due to the DVRT sensor limited accuracy in measuring elongation beyond 3.5 mm., repositioning of the sensor was needed at 45° during DIC tests. Presumably this has influenced the elongation measurement of the DIC and contributed to a slight decrease in elongation around 45° flexion.

In conclusion, the experiments performed suggest that most elongation is seen at the DIC after 3LT. Failure was only observed at the proximal side of the DIC where sutures loosened. These results might indicate the DIC has an important role in stabilizing the scapholunate interval after 3LT. The reconstruction seems to be stable enough to withstand flexion until 30°. Future studies should address earlier start of motion in a clinical setting and study the effect of shorter immobilization.

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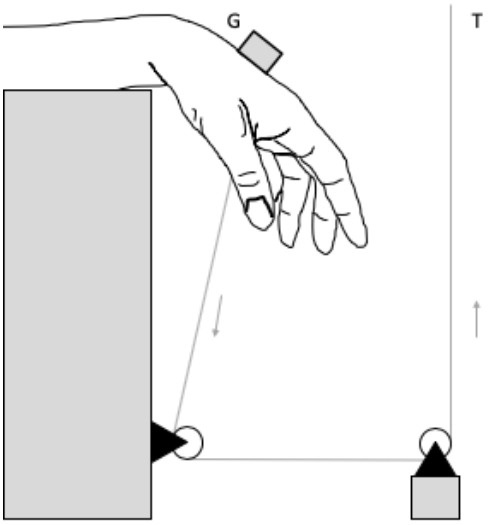
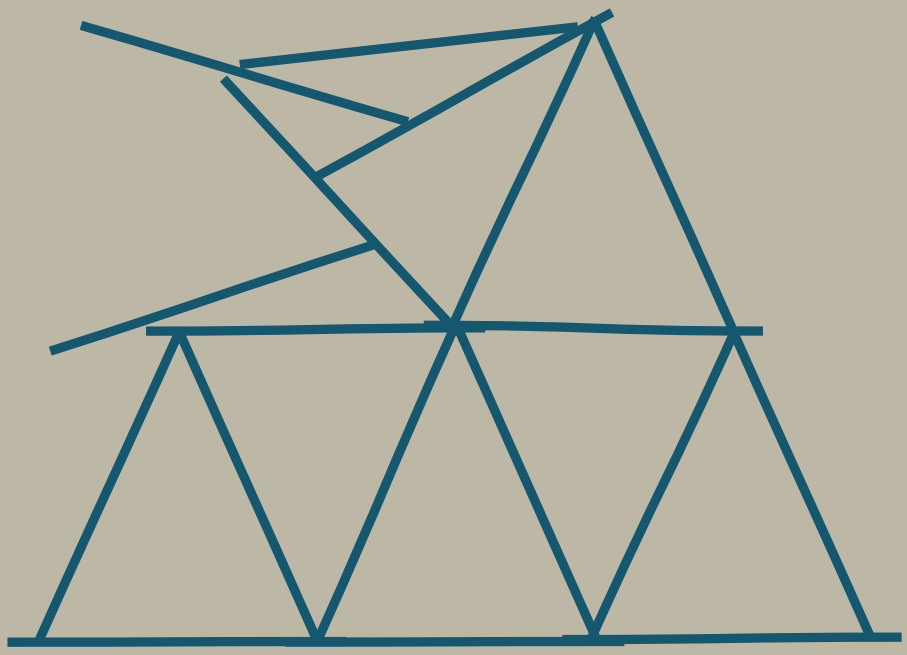


Appendix 1. Schematic overview of testing apparatus. The universal testing machine (T) moved vertically, resulting in palmar flexion of the wrist. A digital goniometer (G) was used to quantify palmar flexion.

Part II

Diagnostics and treatment recommendations for scapholunate ligament injuries.

4 Treatment Recommendations for Suspected Scapholunate Ligament Pathology.



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Abstract

Background
The diagnosis and treatment of scapholunate interosseous ligament (SLIL) pathology is debated and notably variable. This study assessed the influence of diagnostic arthroscopy on treatment recommendations and the interobserver reliability of the arthroscopic classification of SLIL pathology.

Methods
The influence of diagnostic arthroscopy on treatment recommendations and the reliability of the arthroscopic classification of SLIL pathology were tested in a survey-based experiment. Seventy-seven surgeons evaluated 16 scenarios of people with wrist pain with variation in symptoms, scaphoid shift, time of symptom onset, and MRI appearance of the SLIL. Participants were randomized to view or not to view diagnostic wrist arthroscopy. Factors associated with recommendation for repair, capsulodesis, or tenodesis were analyzed.

Results
Viewing arthroscopic videos was associated with both offering surgery and a more reconstructive option. Other factors independently associated with recommendation for surgery included greater pain intensity and activity intolerance, women surgeons, an asymmetric scaphoid shift, and a recent onset of symptoms. The interobserver reliability of SLIL classification was slight.

Conclusions
Diagnostic arthroscopy leads to more surgery, and more invasive surgery, in spite of unreliable assessment of pathology. Clinical Relevance This points to the need to measure the potential benefits and harms of diagnostic wrist arthroscopy among people with wrist pain and no clear diagnosis on interview, examination, and radiographs.

Introduction

Rupture of the scapholunate interosseous ligament (SLIL) is one of the less common injuries that can result from a fall onto an outstretched hand. The proposed mechanism is direct axial compression with the wrist in extension, ulnar deviation, and intercarpal supination.[1] It is relatively unusual to diagnose SLIL rupture acutely. More typically, patients accommodate symptoms for a longer period of time or seek care after another event for which radiographs are obtained and the preexisting pathology is identified. [2–4] Patients with a complete rupture of the SLIL may experience episodic pain. Eventually, they may develop persistent pain related to subsequent osteoarthritis which, in turn, is related to malalignment[5]. Lesser degrees of SLIL pathology have a less clear relationship to symptoms and arthrosis.

Options for the evaluation of suspected ligament injuries of the wrist include examination maneuvers (such as the scaphoid shift test), radiological examinations such as radiographs (including a clenched fist view), computed tomography, magnetic resonance imaging (MRI), cineradiography, and diagnostic wrist arthroscopy.[6,7] The potential benefit and potential harm associated with each of these diagnostic tests is relatively untested. The arthroscopic grading of SLIL pathology reported by Geissler and colleagues is used by some surgeons to direct treatment recommendations.[3,8] Some surgeons consider diagnostic arthroscopy to be the reference standard in the evaluation of SLIL pathology, a position which may contribute to greater use of diagnostic surgery with unclear potential for benefit. For instance, one review of a series of diagnostic wrist arthroscopies reported a very low yield of diagnoses: 80% had no pathological findings or mild synovitis, much of the specific pathophysiology diagnosed were either debatable, potential variations, or likely age-related, and some lesions may have been iatrogenic.[9] Subsequent surgery was offered to only 12% of patients and much of it had questionable value.

It is known that wrist pain is common and can exist without measurable pathology. For instance, young adults with lax ligaments can experience ongoing wrist and anterior knee pain in healthy and structurally sound joints.[10,11] In the circumstance of a low prevalence of pathology such as SLIL rupture, even highly specific and sensitive diagnostic tests can be misleading (Bayes' theorem). Furthermore, there is likely some variation in wrist ligaments and other structures which likely increases with age, expanding the bate rate of accommodated pathology, which, in turn, magnifies the influence of false positive tests and unreliability, thereby increasing the potential for misdiagnosis and unhelpful treatment.[12,13]

To learn more about the role of diagnostic wrist arthroscopy in the evaluation of pain, we performed a survey-based experiment to study the primary null hypothesis that there is no variation in recommended treatment for patients

with suspected SLIL pathology between surgeons that view videos of diagnostic wrist arthroscopy and those that do not, accounting for surgeon and patient characteristics. Secondarily, we addressed the interobserver variability of the classification of SLIL pathology according to Geissler and colleagues as well as factors associated with recommendations for specific surgeries.

Methods

This study was reviewed and approved by the Institutional Review Board.

An email invitation was sent to members of the Science of Variation group (SOVG) with a link to an online survey-based (SurveyMonkey; Palo Alto) experiment about patients seeking care for wrist pain. SOVG studies are experiments conducted by survey. Something is either randomized or

correlated. Because we measure relationships and influences, not rates, the key is adequate variation within the surveyed participants rather than participation rate. Given that we typically address areas of debate and variation in practice, there is usually a wide variation in training, beliefs, and choices among our participants. For hand and wrist topics, we tend to have approximately 65 to 80 participants. Participating surgeons reviewed 16 patient scenarios which contained information about: 1) pain intensity and magnitude of activity intolerance ("the pain is mild and occasional with minimal interference with work and hobbies" or "the pain is substantial and interfering with work and hobbies"), 2) time since onset and potential relatedness to injury ("symptoms started more than a year ago and not clearly related to a specific event" or "symptoms started within a few months and after a fall on an outstretched arm"), 3) scaphoid shift test ("physical examination shows an [either asymmetric or symmetric] scaphoid shift test") and 4) radiological information ("an MRI scan demonstrates a signal change in the scapholunate ligament" or "a normal scapholunate ligament").

All participants read a patient scenario. Half were also randomized to view video recordings of midcarpal and radiocarpal arthroscopic evaluation of the SLIL ligament. Sixteen consecutive videos of wrist arthroscopy in people with a working diagnosis of SLIL insufficiency were obtained from one surgeon's practice. Every year, 120 to 140 patients seek care for suspected SILL pathology from this surgeon. Approximately 40 to 50 (35%) undergo diagnostic arthroscopy and approximately 30 to 40 (27% of the total and 75% of

those having arthroscopy) undergo a reconstructive procedure. All videos were randomly assigned to a patient scenario.

Participants were asked whether they would recommend reconstructive surgery, and if yes, to pick the treatment closest to what they would advise: direct SLIL repair, capsulodesis, or tenodesis. Additionally, all surgeons viewing arthroscopic videos were asked to grade the SLIL pathology, according to the Geissler classification (Table 1).[8] The following explanatory surgeon characteristics were obtained: sex, years of independent practice, supervision of trainees, and region of practice.

Table 1. Geissler classification.

Grade	Description
I	Attenuation/hemorrhage of SLIL as seen from the radiocarpal joint. No incongruency of carpal alignment in the midcarpal space.
II	Attenuation/hemorrhage of SLIL as seen from the radiocarpal joint. Incongruency/step-off as seen from midcarpal space. A slight gap (less than width of a probe) between carpals may be present.
III	Incongruency/step-off of carpal alignment is seen in both the radiocarpal and midcarpal spaces. The probe may be passed through the gap between carpals.
IV	Incongruency/step-off of carpal alignment is seen in both the radiocarpal and midcarpal spaces. Gross instability with manipulation is noted. A 2.7-mm arthroscope may be passed through the gap between carpals.

Participant Characteristics

In total, 88 members of the SOVG initiated the survey and 77 completed it. Thirty-four (44%) participants viewed arthroscopic videos and 43 (56%) only reviewed the patient scenario, and the groups were comparable (Table 2). The concept of response rate is not relevant, since the SOVG participants email list is not filtered or updated, and not all SOVG members treat hand and wrist problems. The sample may or may not be representative of the average hand specialist, but the randomization and statistical analysis otherwise make monitoring relative participation less important. There is sufficient variation among participating surgeons to make the experiment informative and likely applicable to most surgeons.

Table 2. Baseline surgeon characteristics.

Variables	With arthroscopy	Without arthroscopy
Participating surgeons	34 (44%)	43 (56%)
Sex		
Women	7 (21%)	2 (4.7%)
Men	27 (79%)	41 (95%)
Years of independent practice		
0-10	18 (53%)	22 (51%)
>10	16 (47%)	21 (49%)
Supervision to trainees		
Yes	31 (91%)	33 (77%)
No	3 (8.8%)	10 (23%)
Region of practice		
North America	15 (44%)	26 (60%)
Other	19 (56%)	17 (40%)

Discrete variables presented as number (percentage).

Statistical Analysis

Discrete variables were reported as number and percentage, P values <0.05 were considered significant.

The paired t-test was used to compare the difference in the likelihood of recommendation for surgery. Values range from 0 to 1, with 0 indicating that for none of the cases the surgeon recommended surgery, and 1 indicating that for all of the cases, the surgeon recommended surgery. Values are based on the four dichotomous clinical characteristics which are presented and equally divided over the 16 cases, like the symmetric scaphoid shift test (n=8) versus asymmetric scaphoid shift test surgery (n=8).

We created an overall likelihood of recommending surgery score for each surgeon averaging all 16 scenarios and performed a two paired t-test, using likelihoods per patient characteristic of recommending surgery for all cases per surgeon (0-1).

To assess factors independently associated with recommending surgery including viewing arthroscopy and surgeon characteristics, a multilevel multivariable logistic regression was performed.

To determine interobserver variability Cohen's Kappa was used. The Kappa value reflects the degree to which observers agree, considering the chance that observers agree at random. Perfect agreement is represented by a Kappa of 1.00; agreement solely by chance would equate to a Kappa of 0.00 and total disagreement is represented by a Kappa of -1.00. Values between 0.01–0.20 represent none to a

slight agreement, 0.21–0.40 represent fair agreement, 0.41–0.60 represent moderate agreement, 0.61–0.80 represent substantial agreement, and 0.81–1.00 represent almost perfect agreement.[14] To study the surgeon characteristics associated with the interobserver agreement, the differences were observed by comparing the 95% confidence interval of the kappa values per subgroup. To assess factors associated with the type of surgery recommended, a multinomial logistic regression was used.

Results

Accounting for potential confounding using multivariable analysis the following factors were independently associated with recommending operative treatment (Appendix Table A1; Table 3): greater pain intensity and magnitude of activity intolerance (OR 10; 95% CI, 3.5–30; P<0.001); viewing an arthroscopic video (OR 6.9; 95% CI, 2.8–18; P<0.001), women surgeons (OR 4.6; 95% CI, 1.24–17.4; P=0.02); asymmetric scaphoid shift (OR 4.0; 95% CI, 1.4–11; P=0.01); and more recent onset of symptoms after a fall (OR 3.3; 95% CI, 1.1–9.4, P=0.03).

There was slight interobserver reliability of the Geissler classification on video inspection (K=0.18; 95% CI, 0.11–0.26; Table 4). No surgeon characteristics were associated with interobserver reliability.

Table 3. Multilevel multivariable logistic regression analysis of factors associated with recommending surgery.

Independent variables	Odds ratio	95% Confidence interval	Standard error	P value
Arthroscopic video	6.9	2.8 to 18	3.3	**<0.001**
Surgeon characteristics				
Women	4.6	1.24 to 17.4	0.15	**0.02**
>10 years of independent practice	0.56	0.23 to 1.3	0.25	0.19
Giving supervision to trainees	0.75	0.23 to 2.5	0.46	0.63
Region other than North America	2.3	0.96 to 5.5	1.02	0.06
Patient characteristics				
Pain is substantial and interfering with work and hobbies	10	3.5 to 30	5.5	**<0.001**
Symptoms started within a few months and after a fall on an outstretched arm	3.3	1.1 to 9.4	1.8	**0.03**
Asymmetric scaphoid shift test (Watson test)	4.0	1.4 to 11	2.2	**0.01**
MRI scan demonstrates a signal change in the scapholunate ligament	2.8	0.98 to 8.1	1.5	0.06

Bold indicates statistically significant.

Table 4. Interobserver reliability of the Geissler classification.

	Kappa (κ)	95% Confidence interval
Geissler classification	0.18	0.11 to 0.26
Surgeon characteristics		
Sex		
Women	0.13	-0.004 to 0.26
Men	0.19	0.12 to 0.26
Years of independent practice		
0-10	0.16	0.10 to 0.22
>10	0.23	0.12 to 0.34
Giving supervision to trainees		
No	0.28	0.02 to 0.54
Yes	0.18	0.11 to 0.26
Region		
North America	0.15	0.07 to 0.22
Other	0.23	0.13 to 0.33

Multirater kappa indicated by κ.

Viewing arthroscopic videos motivated surgeons to recommend capsulodesis more often than direct repair (RR 0.52; 95% CI, 0.29–0.94; P=0.03) and tenodesis over capsulodesis (RR 2.4; 95% CI, 1.3–4.2; P=0.004; Table 5) relative to surgeons that did not view videos. Surgeons from other regions than North America recommended significantly more capsulodesis than direct repair (RR 0.31; 95% CI, 0.18–0.55; p=<0.001). Giving supervision to trainees resulted in more recommendations for direct repair compared to capsulodesis (RR 6.8; 95% CI, 2.6–18; p=<0.001). Recommending tenodesis over capsulodesis was also associated with supervision of trainees (RR 2.3; 95% CI, 1.1–5.0; P=0.03; Table 5).

Table 5. Multinomial logistic regression of factors associated with type of surgery.

Dependent variables	Independent variables	Relative risk ratio	95% Confidence interval	Standard error	P value
Direct repair compared to capsulodesis	Arthroscopic video	0.52	0.29 to 0.94	0.16	**0.03**
	Men	0.94	0.46 to 1.9	0.33	0.85
	>10 years of independent practice	1.02	0.58 to 1.8	0.29	0.95
	Giving supervision to trainees	6.8	2.6 to 18	3.4	**<0.001**
	Region other than North America	0.31	0.18 to 0.55	0.09	**<0.001**
Tenodesis compared to capsulodesis	Arthroscopic video	2.4	1.3 to 4.2	0.70	**0.004**
	Men	0.74	0.40 to 1.4	0.23	0.34
	>10 years of independent practice	0.66	0.39 to 1.1	0.18	0.12
	Giving supervision to trainees	2.3	1.1 to 5.0	0.92	**0.03**
	Region other than North America	1.1	0.65 to 1.9	0.30	0.72

Bold indicates statistically significant.

Discussion

The diagnosis and treatment of SLIL pathology is a subject of debate with substantial specialist-to-specialist variation in care [15–17]. This study identified that viewing diagnostic wrist arthroscopy rather than clinical findings led to a significant increase in recommendation for surgery. Even though the interpretation of SLIL pathology on arthroscopy was not reliable, viewing a video resulted in more frequent and more invasive treatment recommendations.

This study has several limitations. First, consecutive arthroscopic videos were collected from one hand surgeon. This surgeon's referral practice, assessment, and indications for diagnostic wrist arthroscopy may or may not be representative of the average surgeon. For the purposes of this experiment, it suffices that there was sufficient variation in pathology in the 16 videos. Second, all videos were randomly allocated to a fictional scenario. This might result in unlikely combinations. In our opinion, uncommon and even unlikely combinations are seen in practice and can be considered representative. Third, clinicians might consider unavailable information important. For practical statistical considerations, only four factors plus arthroscopy or no arthroscopy were studied. Using only four factors is a simplification of the clinical practice. Readers can consider this experiment as measuring the relative influence of these factors. Future experiments can address more and other factors felt to be important. Fourth, fewer surgeons randomized to review the arthroscopic videos completed the survey. It is possible that reviewing videos was more effort and people were less willing to invest that time, which could introduce some bias. In our opinion, a sufficient number of surgeons completed the survey and that group had sufficient variation to allow the experiment to identify factors associated with the variation.

The finding that viewing videos of diagnostic arthroscopy led to more recommendation for surgery independent of surgeon and patient factors may reflect the influence of several well-known human cognitive biases (systematic errors in thinking) such as confirmation bias (giving greater weight to findings that support our belief), information bias (the tendency to seek information even when it cannot affect outcomes), prospect theory (the tendency to make riskier choices to avoid negative outcomes), and sunk cost effects (continuing a behavior as a result of previous invested resources, in this case "we were willing to do surgery for diagnosis, we might as well keep going and do surgery for treatment"). There is evidence that surgeons are as prone to such biases as other humans, and that they may be no better at employing effective de-biasing strategies to neutralize their influence.[18]

Some authors suggest that investigation of possible pathology is incomplete without wrist arthroscopy, while others point to evidence that nonspecific examination findings and reassuring radiographs are sufficient.[9,19–21] Continuing the important consideration of cognitive bias, the proposition that diagnostic wrist arthroscopy as the reference standard could sets up a framing heuristic that sets the level of acceptable uncertainty very low, which introduce the potential for iatrogenic, psychological, and financial harm. It is known that people experiencing notable symptoms can often be less accepting of uncertainty, or place inordinate hope on finding and fixing pathology.[22,23] It would help to experimentally measure the following factors in order to evaluate the relative benefit of imaging and diagnostic surgery among people with nonspecific (reassuring exam and radiographs) ongoing wrist pain: reliability, accuracy, posttest changes in probability of diagnosis and potential benefits and harms. It seems plausible that a simpler strategy using examination and radiographs alone will lead to greater health.

The finding that notable symptom intensity and magnitude of activity limitations had the strongest influence on the recommendation for surgery may reflect specialist unfamiliarity with the evidence of the notable influence of thoughts, emotions, and circumstances on human illness (biopsychosocial paradigm of human illness behavior) and the relative lack of correspondence of symptoms with objective pathology (biomedical model). More intense symptoms and relative incapability can signal musculoskeletal specialists to look for common misconceptions about symptoms, as well as notable symptoms of stress and distress. This is an important step in order to avoid misdiagnosing the illness and overutilizing potentially distracting and unhelpful reconstructive surgery.[24–26]

The observation that video diagnosis of Geissler grade of pathology had slight interobserver reliability (κ=0.18), independent of surgeon characteristics, is

consistent with and even lower than a prior study measuring fair interobserver reliability (κ=0.34) of three surgeons interpreting photographs and videos of wrist arthroscopy.[27,28] The current study used a larger sample of surgeons and could therefore be considered more representative. The low reliability makes it difficult to support management strategies based on these grades of pathology.

The observation that viewing an arthroscopic video was associated with moving up the reconstructive stepladder to more tenodesis compared to capsulodesis and more capsulodesis compared to direct repair reflects a strong influence of arthroscopy that merits testing for potential benefits compared with potential harms. Do surgeons make recommendations that lead to better outcomes based on wrist arthroscopy or is wrist arthroscopy contributing to unhelpful tendencies to be more interventional and causing greater alternation of anatomy without measurable benefit?

In conclusion, our experiments measured strong influences of wrist arthroscopy and symptom intensity on recommendations for reconstructive surgery and for more anatomy-altering surgery while showing that the interpretation of SLIL pathology was unreliable. These types of studies manifest the cognitive biases that affect the surgeon mind. Such cognitive biases are almost certainly a source of surgeon-to-surgeon variations in care for wrist pain and other conditions. To improve the quality of care, reduce unwarranted variation, and increase alignment with patient values and preferences, surgeons can anticipate such biases and incorporate debiasing tactics into their care strategies. For instance, surgeon awareness that a decision for diagnostic wrist arthroscopy creates a bias towards reconstructive surgery, regardless of the potential benefits or harms of that surgery, and even though what is seen on arthroscopy is unreliably interpreted, might alter the circumstances in which diagnostic wrist arthroscopy is offered. Surgeons can also learn to anticipate common misconceptions as a component of notable symptom intensity and magnitude of activity intolerance and prepare for communication strategies that can help guide people to a more accurate understanding of their condition. These possibilities merit additional study.

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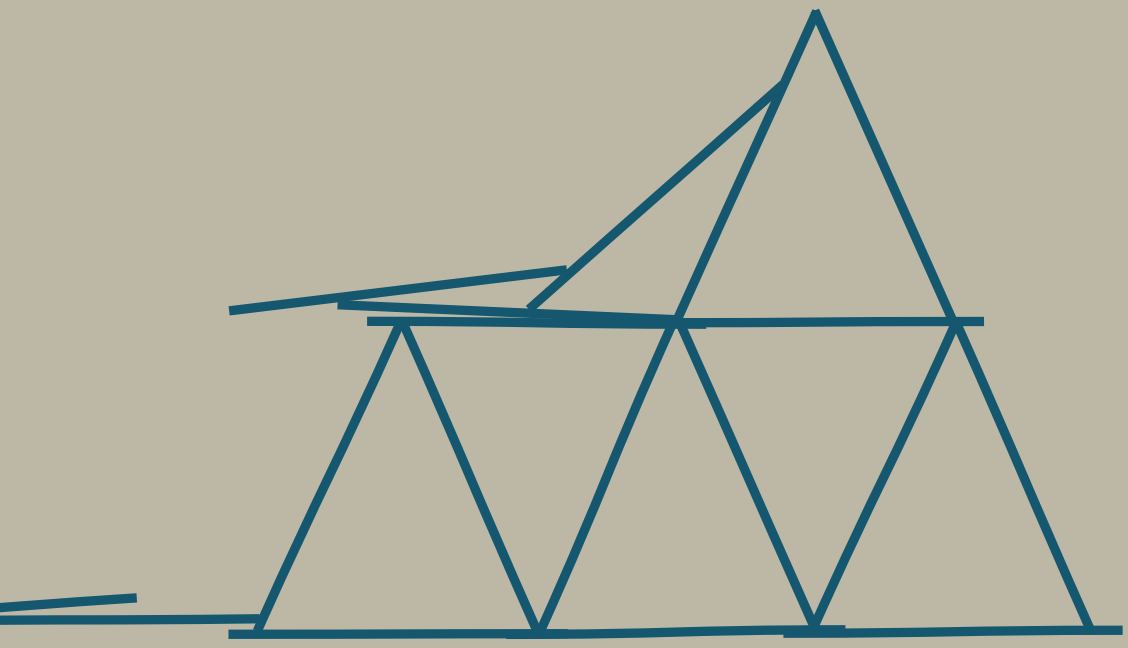
Appendix 1. Patient characteristics leading to recommending surgery.

Variables	Recommending surgery	P value
Overall	0.30 ± 0.24	
Pain		
Pain is mild and occasional with minimal interference with work and hobbies	0.18 ± 0.21	**<0.001**
Pain is substantial and interfering with work and hobbies	0.42 ± 0.33	
Symptoms		
Symptoms started more than a year ago and not clearly related to a specific event	0.25 ± 0.22	**<0.001**
Symptoms started within a few months and after a fall on an outstretched arm	0.35 ± 0.29	
Watson test		
Symmetric scaphoid shift test (Watson test)	0.23 ± 0.22	**<0.001**
Asymmetric scaphoid shift test (Watson test)	0.38 ± 0.29	
MRI		
MRI scan demonstrates a normal scapholunate ligament	0.25 ± 0.28	**0.001**
MRI scan demonstrates a signal change in the scapholunate ligament	0.35 ± 0.27	

Bold indicates statistically significant. Recommendation for surgery from 0 indicating no surgery to 1 indicating surgery.

5 Is Midcarpal Arthroscopy for Suspected Scapholunate Pathology Associated with Greater Interobserver Agreement and More Frequent Offer of Surgery?



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Abstract

Purpose

This study compared the interobserver agreement of arthroscopic classification of suspected scapholunate interosseous ligament (SLIL) pathology with and without midcarpal arthroscopy to help inform diagnostic strategies. It also measured the association of midcarpal arthroscopy with recommendations for reconstructive surgery. The association of midcarpal arthroscopy with the type of surgery recommended was also studied.

Methods

Fourteen consecutive videos of diagnostic radiocarpal and midcarpal wrist arthroscopy for suspected SLIL pathology were selected. An international survey-based experiment was conducted among upper extremity surgeons of the Science of Variation Group. Participants were randomized to view either radiocarpal arthroscopic videos or radiocarpal and midcarpal videos. Surgeons rated SLIL pathology according to the Geissler classification and recommended surgical or nonsurgical treatment. If surgical treatment was recommended, they indicated the type of procedure.

Results

The interobserver agreement for the Geissler classification was slight/fair for observers who reviewed midcarpal and radiocarpal videos and for those who viewed radiocarpal videos only. Viewing midcarpal videos was associated with higher pathology grades, the recommendation for reconstructive surgery, and a preference for tenodesis over scapholunate ligament repair.

Conclusions

Diagnostic wrist arthroscopy for a wrist with normal radiological alignment has poor interobserver agreement.

Clinical relevance:

The pursuit of a pathology that accounts for wrist symptoms in a nonspecific interview and examination and normal radiographs is understandable; however, the low reliability of the scapholunate pathology of diagnostic arthroscopy might be associated with more potential harm than benefit.

Introduction

Given the limited reliability and accuracy of imaging, many specialists consider wrist arthroscopy to be important for the diagnosis of scapholunate interosseous ligament (SLIL) pathology.[1,2] Scapholunate interosseous ligament pathology can be visualized and probed directly using radiocarpal arthroscopy. Midcarpal arthroscopy can be used to evaluate SLIL pathology by evaluating static and dynamic carpal relationships.[3–8]

Arthroscopic findings are usually classified using the levels suggested by Geissler and colleagues ranging from attenuation or hemorrhage of the SLIL with congruency of the lunate and scaphoid (grade I) to gross instability with a gap of 2.7 mm (arthroscope width) or more (grade IV).[8,9] Prior studies examining the reliability of wrist arthroscopy for diagnosing SLIL pathology (2 studies) or triangular fibrocartilage pathology (1 study) have reported a slight-to-fair interobserver agreement.[10–12] In 1 study, 3 surgeons interpreting midcarpal and radiocarpal photographs of wrist arthroscopy found fair interobserver agreement for the classification of scapholunate ligament pathology.[11] In another study, 77 surgeons, randomized to view or not view videos of wrist arthroscopy in addition to information about symptoms, signs, and imaging, reported slight interobserver agreement among the 34 surgeons that classified SLIL pathology.[10]

Some authors advocate midcarpal arthroscopy in addition to radiocarpal arthroscopy.[13,14] In 1 study, substantially more pathology was diagnosed after midcarpal arthroscopy than radiocarpal arthroscopy alone.[14] Given the previously reported slight-to-fair interobserver agreement, the potential benefits and harms of midcarpal arthroscopy and its associated diagnoses merit additional study. One potential harm is that ordering and interpreting a diagnostic test can be associated with more diagnoses and medical care regardless of the results or diagnostic performance characteristics of the test.[15] Increases in the rate or invasiveness of therapeutic procedures expose people to potential iatrogenic, psychologic, and financial harms.[16]

As the next step in this line of research, we addressed the concept that a combination of midcarpal and radiocarpal arthroscopy can improve the interobserver agreement of pathology grade compared with radiocarpal arthroscopy alone. Furthermore, although mindful of the notable variation in treatment recommendations even when scapholunate pathology is indisputable, we tested whether treatment recommendations differed between surgeons who were presented with the radiocarpal view alone and those who presented with both radiocarpal and midcarpal views, independent of the reliability of grading SLIL pathology. Our interest was whether a greater volume and variety of information (in this case, videos) is associated with recommending more invasive treatment and an

associated increase in reliability or accuracy. For instance, some prior studies have found that additional computed tomography reconstructions lead to more invasive treatment recommendations, without appreciable improvements in reliability.[17–19] Such a finding might reveal a potential for harm associated with diagnostic tests.[20]

We tested the primary null hypothesis that there is no difference in interobserver agreement according to the classification proposed by Geissler and colleagues between surgeons who viewed only radiocarpal videos and those who viewed radiocarpal and midcarpal videos. Additionally, we tested the secondary null hypotheses that there is no difference in pathology grade; the recommendation for additional surgery; and the procedure recommended between surgeons who viewed radiocarpal and midcarpal

arthroscopy videos and those who viewed the radiocarpal view alone, accounting for surgeon characteristics.

Materials and methods

Study design and setting

This work was performed at the University of Texas at Austin, Austin, Texas. This study was approved by University of Texas institutional review board. Fourteen consecutive radiocarpal and midcarpal wrist arthroscopy videos of patients presenting for suspected SLIL pathology were obtained from a single surgeon's practice. Consecutive patients were used because examination and imaging identified no abnormalities on which to categorize pathology, the arthroscopic diagnosis was the focus of the study, and there is no reference standard for accuracy of the classification of SLIL pathology. Therefore, there was no way to choose a representative distribution of pathology to limit spectrum bias. In this circumstance, a consecutive sample reduces the possibility of selection bias. All the included patients had wrist pain at the scapholunate interval and a positive scaphoid shift test result, which can be abnormal in healthy wrists.[21] Most had a ring sign on their clenched fist radiograph, which can be an incidental finding and exist in a range of wrist positions; however, none had widening of the scapholunate interval.[22] Symptoms were monitored for at least 6 months before diagnostic arthroscopy was offered.

We created an international survey-based experiment (SurveyMonkey), which was iteratively piloted by a subgroup of the authors until a clear and workable survey was achieved. All hand and upper extremity surgeons of the Science of Variation Group (SOVG) participated. The SOVG is an international collaborative of orthopedic, hand, and fracture surgeons interested in studying variations in

care. The experiments conducted with the SOVG primarily rely on the diversity of responses within the sample and are less influenced by the participation rate. For a given case, participants were randomized to review either radiocarpal arthroscopic videos or radiocarpal and midcarpal videos. Participants could replay, slow down, or pause the videos at any time.

Measured variables

As our primary outcome, surgeons were asked to grade the SLIL pathology according to the (modified) Geissler classification: attenuation or hemorrhage of the SLIL with congruency of the lunate and scaphoid is rated as grade I; attenuation or hemorrhage of the SLIL with step-off and/or gap between 1 and 2 mm between the lunate and scaphoid signifies grade II; a step-off and/or gap of more than a probe width (2 mm) is grade III; and gross instability with a gap of 2.7 mm (arthroscope width) or more is rated as grade IV.

For our secondary response variables, observers were asked whether they would recommend surgery. If observers recommended surgery, they were prompted to choose the surgical option closest to what they would advise from the following 3 commonly performed procedures: direct SLIL repair, capsulodesis, and tenodesis.[5] In asking this, we were mindful of the notable variation in treatment recommendations for undisputed scapholunate ligament pathology. Our interest was whether additional information is associated with more invasive treatment, independent of whether this additional information improves reliability or accuracy.

Participant characteristics

A total of 60 surgeons completed the survey (Table 1). Twenty-nine (48%) surgeons were randomized by the survey tool to review the midcarpal and radiocarpal videos, and 31 (52%) reviewed the radiocarpal videos only. Most surgeons (36, 60%) practiced in the United States, and most (49, 82%) subspecialized in hand and wrist surgery. The number of participants and their practice characteristics were comparable to prior SOVG studies of wrist conditions.[23,24]

Table 1. Surgeon Demographics*

	Midcarpal view	
Value	Yes	No
N	29 (48%)	31 (52%)
Male	25 (86%)	31 (100%)
Continent		
United States	18 (59%)	18 (58%)
Europe	8 (28%)	10 (32%)
Other	4 (14%)	3 (9.7%)
Years of experience		
0-5	10 (34%)	5 (16%)
6-10	5 (17%)	7 (23%)
11-20	8 (28%)	12 (39%)
>20	6 (21%)	7 (23%)
Supervising	24 (83%)	23 (74%)
Subspecialty		
Hand and wrist	24 (83%)	25 (81%)
Other	5 (17%)	6 (19%)

*Categorical variables are presented as number (percentage).

Statistical Analysis

Categorical variables were reported as numbers (percentages). To measure interobserver agreement, the Fleiss' k was calculated using bootstrapping (resamples ¼ 1000) to calculate the standard error, z statistic, and 95% confidence intervals. Kappa values range between 0 and 1, with 0 representing agreement solely on the basis of chance, whereas 1 represents perfect agreement. To interpret the k values, we used the classification of Landis and Koch: values between 0.01 and 0.20 represent "slight" agreement; values between 0.21 and 0.40 represent "fair" agreement; values between 0.41 and 0.60 represent "moderate" agreement; values between 0.61 and 0.80 represent "substantial" agreement; and values greater than 0.81 represent "near-perfect" agreement.[25] Differences in Geissler grades by arthroscopic view were compared for each case using Chi2 tests. Surgeon and arthroscopic

factors associated with the Geissler grade were assessed using a multilevel ordinal logistic regression, accounting for nesting on a patient level because we expected a priori that the midcarpal view had differing effects for each patient.

Similarly, the rate of surgery and type of procedure were reported by an arthroscopic view for each patient and compared using Fisher exact and Chi2 tests, where appropriate. We constructed a multilevel logistic regression model, seeking factors associated with the recommending type of surgical treatment, accounting for

nesting by cases. Finally, a multinomial logistic regression model was constructed, seeking factors associated with the recommended procedure. Odds ratios, standard errors, relative risk ratios, and *P* values were reported. All *P* values below .05 were considered significant.

Results

The interobserver agreement of the Geissler classification was comparably poor for observers who reviewed the midcarpal and radiocarpal videos (κ=0.21 [fair]; 95% CI, 0.10 – 0.32; Table 2) and for observers who viewed radiocarpal videos only (κ=0.18 [slight]; 95% CI, 0.076 – 0.28) (*P*=0.71; Table 2). There were no differences in interobserver agreement in the subgroup analyses.

Table 2. The Interobserver Agreement of the Geissler Classification for Scapholunate Ligament Pathology by Arthroscopic View and Surgeon Characteristics*

	Midcarpal view Kappa (95% Confidence Interval)		**P value**
Characteristics	**Yes**	**No**	
All surgeons	0.21 (0.10 to 0.32)	0.18 (0.076 to 0.28)	.71
Continent			
United states	0.21 (0.099 to 0.31)	0.21 (0.096 to 0.32)	.96
Other	0.24 (0.071 to 0.41)	0.13 (0.026 to 0.24)	.30
Years of experience			
≤10	0.20 (0.081 to 0.32)	0.22 (0.070 to 0.37)	.84
>10	0.21 (0.083 to 0.34)	0.16 (0.060 to 0.26)	.52
Supervising			
Yes	0.21 (0.098 to 0.33)	0.18 (0.075 to 0.28)	.66
No	0.13 (-0.033 to 0.30)	0.32 (0.14 to 0.49)	.15
Subspecialty			
Hand and wrist	0.19 (0.088 to 0.30)	0.20 (0.099 to 0.31)	.89
Other	0.21 (-0.0015 to 0.43)	0.19 (0.077 to 0.31)	.87

Bold entries indicate significance, P < .05.

Accounting for potential confounders in multivariable analysis, higher Geissler grades were independently associated with viewing midcarpal in addition to radiocarpal videos, 0 to 5 years of experience, and supervising trainees (Table 3).

Table 3. Multilevel Ordinal Logistic Regression Analysis of Factors Associated with the Geissler Grade, Accounting for Nesting on a Patient Level

	Odds Ratio (95% Confidence Interval)	Standard Error	P-value
Midcarpal view			
Absent	*reference value*		
Present	1.5 (1.1-2.0)	0.23	**.014**
Gender			
Woman	*reference value*		
Man	0.77 (0.40-1.5)	0.26	.44
Continent			
United States	*reference value*		
Other	1.0 (0.77-1.4)	0.16	.81
Years of experience			
0-5	*reference value*		
6-10	0.58 (0.37-0.92)	0.14	**.021**
11-20	0.39 (0.26-0.60)	0.090	**<.001**
>20	0.45 (0.29-0.72)	0.11	**.001**
Supervising			
No	*reference value*		
Yes	2.1 (1.4-3.2)	0.44	**<.001**
Subspecialty			
Hand and wrist	*reference value*		
Other	1.2 (0.83-1.8)	0.23	.33

Bold entries indicate significance, $P < .05$

There was substantial variation in the Geissler grade by arthroscopic view for almost half the patients (7 out of 14 [50%]; Appendix A).

Accounting for potential confounders, a recommendation for surgical treatment was associated with presenting the midcarpal view, supervising trainees, and the subspecialty 'other' (Table 4).

Table 4. Multilevel Logistic Regression Analysis of Factors Associated With Recommending Surgical Treatment, Accounting for Nesting on a Patient Level*

	Odds Ratio (95% Confidence Interval)	Standard Error	P-value
Midcarpal view			
Absent	*reference value*		
Present	1.8 (1.3-2.7)	0.36	**.003**
Gender			
Female	*reference value*		
Male	0.53 (0.25-1.2)	0.21	.11
Continent			
United States	*reference value*		
Other	1.2 (0.80-1.7)	0.23	.40
Years of experience			
0-5	*reference value*		
6-10	0.83 (0.48-1.5)	0.24	.51
11-20	0.66 (0.39-1.1)	0.18	.13
>20	0.31 (0.17-0.57)	0.085	**<.001**
Supervising			
No	*reference value*		
Yes	1.7 (1.0-2.9)	0.45	**.045**
Subspecialty			
Hand and wrist	*reference value*		
Other	2.0 (1.3-3.2)	0.49	**.004**

***Bold** entries indicate significance, $P < .05$.

Having more than 20 years of experience was associated with a lower likelihood of offering surgery. The rate of a recommendation for surgery was significantly different in 6 out of 14 patients (43%) by arthroscopic view and resulted in a higher overall recommendation for surgical treatment (41% vs. 30%; P=0.002; Appendix B).

Presentation of the midcarpal view was associated with recommending tenodesis over scapholunate ligament repair, and there were some differences in treatment recommendations by region and years in practice (Appendix C).

Discussion

As the diagnostic accuracy of provocative wrist tests, radiographs, and MRI in diagnosing ligament injuries is limited, many surgeons consider wrist arthroscopy the reference standard in grading intercarpal pathology.[4,26,27] There is a gap in evidence regarding the potential benefits and potential harms of using midcarpal arthroscopy in addition to radiocarpal arthroscopy for diagnosis and grading of SLIL pathology among people with symptoms and signs suggestive of insufficiency. Our survey-based experiment found that midcarpal arthroscopy did not improve interobserver agreement regarding pathology grade.

This study has several limitations. First, the videos represent a consecutive sample from a single hand surgeons' practice in an attempt to limit spectrum bias. Surgeon indications for diagnostic wrist arthroscopy differ, and these videos may or may not generalize to the pathology seen by the average surgeon. For the purposes of this experiment there was sufficient variation in pathology for a viable experiment regarding the effect of midcarpal arthroscopy on pathology grade. Second, viewing arthroscopic videos lacks the haptic feedback of actual arthroscopy. We used clips that demonstrate manipulation of the ligament and the bones and feel that it was representative of actual arthroscopy. Third, surgeons were not able to speak to or examine the patient, which might reduce variation between surgeons. Survey experiments cannot mimic the complexity of patient interaction. One can argue that such complexity might introduce even more variation between surgeons, because surgeons may vary in their interpretation of symptoms and their consideration of the patient's interpretation of the symptoms, and they may also vary in both how they conduct the physical examination and how it is interpreted. We value these experiments for trying to reduce the variation from these other aspects and focus on how a limited amount of additional information might influence variation between surgeons. The setting of this study—diagnostic uncertainty based on interview, exam, and radiological tests—seems well suited to the scenario experiment setting since those factors should be neutralized. Fourth, it would be interesting to know whether midcarpal arthroscopy helps distinguish complete SL insufficiency (grade IV) from partial SL insufficiency (grades I-III), as the former is associated with progressive arthrosis and the latter may not be.[28] Since our data included people with nonspecific wrist pain and normal imaging, there is not enough high-grade pathology to study whether reliability is greater with complete rupture. Fewer than 10% of ratings were grade IV (Appendix A). Perhaps, this question is not interesting given that complete SLIL rupture is typically evident on standard radiographs and is less likely to go undetected prior to arthroscopy.[29,30] Arthroscopy seems to be used based on a rationale that diagnosing and treating lesser grades of SLIL pathology has more potential for benefit than for harm which is yet to be determined. It may be that stopping the diagnostic quest and accepting a small amount of uncertainty is a more healthful strategy.[31]

The observation that interobserver agreement on ratings of SLIL pathology was limited, regardless of the availability of the midcarpal view, suggests that additional visual information does not improve the observer agreement of classification of pathology. Other studies of arthroscopic classification of scapholunate ligament pathology have shown similarly limited reliability.[10,11] It may seem counterintuitive that more detailed information and even direct visualization does not lead to greater reliability with classification. Using one example of classification of proximal humerus fractures, the reliability observed for small groups of researchers at one institution was not reproduced[32], and the reliability of classification was not notably improved by more detailed imaging[17] or simplification of the classification, or training the observers.[33] We assume this relates to cognitive science and all of the factors that contribute to varied interpretation of images.[34] The absence of a measurable influence from midcarpal arthroscopy images, and the association of more severe grades of pathology with fewer years of experience and supervision of trainees suggests that the discernment of relatively nuanced grades of pathology may be influenced by surgeon factors. For instance, the results might be different among a select group of experienced wrist arthroscopy experts. It might also be influenced by factors such as opinions about the pathology and its treatment as well as the mind's systematic interpretation tendencies (cognitive bias). This is consistent with evidence that more sophisticated imaging and even training has little influence on inter observer agreement.[11,35,36]

The finding that midcarpal arthroscopy was associated with higher grading of pathology, more recommendations for surgery, and recommendations for more invasive surgery might reflect the potential for a larger amount of diagnostic information to add diagnoses and treatments without improving health.[15] This phenomenon is well-studied in cancer screening where testing in performed in a low prevalence settings or when the cancers diagnosed are not dangerous is clearly associated with potential psychological, financial, and iatrogenic harm.[20] For instance, increased diagnosis of thyroid and renal cancer has not affected mortality, but it has led to more treatment and more people that live with cancer.[20] While cancer screening is clearly a higher stakes scenario and discretionary surgery to alleviate wrist pain, these compelling data highlight how diagnosis alone can expose a person to harm. While it's possible that midcarpal arthroscopy is providing useful information, we must also consider that that it might make patients and surgeons more concerned without improving observer agreement or accuracy, which may expose people to greater potential for harm than for benefit. If another study provides experimental evidence that the recommended reconstructive surgeries have more potential for benefit than for harm, then the finding that more diagnostic information leads to more reconstructive surgery can be considered beneficial. If, on the other hand, a study comparing diagnostic approaches shows no benefit to diagnostic surgery or the resulting reconstructive

surgery recommendations relative to people who accept uncertainty regarding their wrist pain, then a diagnostic surgery strategy would be considered to have more potential for harm.

The finding that midcarpal arthroscopy leads to worse grading of pathology is in line with a study in which three surgeons evaluated 81 wrists for interosseous ligament insufficiency and found that midcarpal arthroscopy added or increased the rating of instability in 67 of 81 wrists (83%).[14] What's left to determine is whether these ratings for more severe pathology are associated with more potential for benefit than for harm. It's possible that a diagnostic surgery strategy leads to useful diagnoses and interventions that improve health. It is also possible that diagnostic surgery exposes people to a combination of iatrogenic harm, debatable diagnoses, and unhelpful reconstructive surgeries that can harm their health. One retrospective review of 135 diagnostic wrist arthroscopies among patients with nonspecific wrist pain, including "suspected SLIL pathology" reported that most patients had no pathology or mild synovitis (78%) and many others had likely age related changes (13%).[37] Six percent were given uncommon diagnoses that are open to debate and 4% had osteochondral defects that may have been iatrogenic. Twelve patients had additional surgery based on the diagnoses.[37] If exposure to these diagnoses (6 of 135) and additional surgeries (12 of 135) provided benefit, that would represent a low yield of benefit for diagnostic surgery, and patients and surgeons could decide together if this is worthwhile. If, on the other hand, the additional diagnoses and surgery recommendations exposed people to greater potential for harm than for benefit, then we would likely abandon diagnostic surgery.

The limited yield of treatable pathology from diagnostic wrist arthroscopy among patients with nonspecific wrist pain, in combination with our current findings of low interobserver agreement, higher grades of pathology and more recommendations for surgery with midcarpal arthroscopy, suggests patients and surgeons should be aware of the possibility that diagnostic arthroscopy might have greater potential for harm than for benefit in the setting of where symptoms are prominent and pathology is limited or absent—an area for ongoing study.[37] The health value of accommodating health conditions should not be underestimated or undervalued, and clinicians can work towards equitable access to accommodation. Data from population-based studies, large randomized trials, and placebo and nocebo effects confirm that accommodation can be a very effective health strategy.[38,39] The foundation of effective accommodation seems to be healthy thoughts and limited stress and distress.[40,41]

In conclusion, this survey-based experiment found that among patients with nonspecific wrist pain and radiographic appearance, midcarpal arthroscopy does not increase interobserver agreement and is associated with higher pathology

grades. In this limited pathology scenario, it remains to be determined whether diagnostic surgery, and greater levels of diagnostic information such as adding midcarpal arthroscopy, have more potential for benefit than for harm. If diagnostic surgery introduces greater variation in interpretation of pathology severity, it may have the potential to reinforce unwarranted clinician-level variation in treatment recommendations.

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Appendix A. Variation in Geissler grade by arthroscopic view.

Case	Midcarpal view	Geissler type I	Geissler type II	Geissler type III	Geissler type IV	*P*-value
1	yes	3 (10%)	12 (41%)	12 (41%)	2 (6.9%)	**0,006**
1	no	15 (48%)	11 (35%)	4 (13%)	1 (3.2%)	
2	yes	3 (11%)	14 (52%)	8 (30%)	2 (7.4%)	0,24
2	no	7 (25%)	11 (39%)	10 (36%)	0 (0%)	
3	yes	22 (85%)	4 (15%)	0 (0%)	0 (0%)	**0,002**
3	no	10 (38%)	13 (50%)	3 (12%)	0 (0%)	
4	yes	14 (54%)	8 (31%)	4 (15%)	0 (0%)	0,24
4	no	19 (73%)	6 (23%)	1 (3.9%)	0 (0%)	
5	yes	22 (85%)	4 (15%)	0 (0%)	0 (0%)	>0.99
5	no	22 (85%)	4 (15%)	0 (0%)	0 (0%)	
6	yes	1 (3.9%)	10 (38%)	14 (54%)	1 (3.9%)	**0,002**
6	no	9 (35%)	14 (54%)	3 (12%)	0 (0%)	
7	yes	4 (15%)	11 (42%)	10 (38%)	1 (3.9%)	0,077
7	no	11 (42%)	11 (42%)	4 (15%)	0 (0%)	
8	yes	11 (42%)	11 (42%)	4 (15%)	0 (0%)	0,23
8	no	9 (35%)	16 (62%)	1 (3.9%)	0 (0%)	
9	yes	6 (23%)	6 (23%)	13 (50%)	0 (0%)	0,37
9	no	3 (12%)	10 (38%)	13 (50%)	0 (0%)	
10	yes	14 (54%)	10 (38%)	0 (0%)	1 (3.9%)	**0,002**
10	no	3 (12%)	14 (54%)	7 (27%)	2 (7.7%)	
11	yes	0 (0%)	0 (0%)	9 (36%)	16 (64%)	**0,011**
11	no	0 (0%)	2 (7.7%)	17 (68%)	6 (24%)	
12	yes	2 (7.7%)	8 (32%)	13 (52%)	2 (8.0%)	**<0.001**
12	no	10 (38%)	14 (54%)	1 (3.9%)	0 (0%)	
13	yes	0 (0%)	5 (20%)	15 (60%)	5 (20%)	0,19
13	no	0 (0%)	3 (12%)	11 (44%)	11 (44%)	
14	yes	7 (28%)	12 (48%)	5 (20%)	1 (4.0%)	**0,027**
14	no	17 (68%)	7 (28%)	1 (4.0%)	0 (0%)	
Total	yes	109 (30%)	115 (32%)	107 (30%)	31 (8.6%)	**0,007**
	no	135 (37%)	136 (37%)	76 (21%)	20 (5.4%)	

Bold indicates statistical significance, P < 0.05.

Appendix B. Variation in the rate and type of operative treatment by arthroscopic view.

Case	Mid-carpal view	Surgical treatment	P-value	Scapholunate ligament repair	Tenodesis	Capsulodesis	*P*-value
1	yes	15 (52%)	**0.014**	10 (67%)	2 (13%)	3 (20%)	0.050
1	no	6 (19%)		3 (50%)	2 (33%)	1 (17%)	
2	yes	14 (52%)	0.59	6 (43%)	4 (29%)	4 (29%)	0.74
2	no	12 (43%)		5 (42%)	2 (17%)	5 (42%)	
3	yes	0 (0%)	**0.004**	0 (0%)	0 (0%)	0 (0%)	**0.035**
3	no	8 (31%)		3 (38%)	3 (38%)	2 (25%)	
4	yes	3 (12%)	>0.99	0 (0%)	1 (33%)	2 (67%)	0.49
4	no	2 (7.7%)		1 (50%)	1 (50%)	0 (0%)	
5	yes	1 (3.9%)	>0.99	0 (0%)	0 (0%)	1 (100%)	0.40
5	no	2 (7.7%)		1 (50%)	1 (50%)	0 (0%)	
6	yes	18 (69%)	**0.001**	9 (50%)	5 (28%)	4 (22%)	**0.002**
6	no	5 (19%)		1 (20%)	3 (60%)	1 (20%)	
7	yes	12 (46%)	0.075	3 (25%)	5 (42%)	4 (33%)	**0.035**
7	no	5 (19%)		4 (80%)	1 (20%)	0 (0%)	
8	yes	2 (7.7%)	0.99	1 (50%)	0 (0%)	1 (50%)	0.81
8	no	3 (12%)		1 (33%)	1 (33%)	1 (33%)	
9	yes	12 (48%)	0.99	4 (33%)	4 (33%)	4 (33%)	0.77
9	no	12 (46%)		6 (50%)	4 (33%)	2 (17%)	
10	yes	3 (12%)	**0.013**	2 (67%)	0 (0%)	1 (33%)	0.14
10	no	12 (46%)		6 (55%)	1 (9.1%)	4 (36%)	
11	yes	23 (92%)	0.42	4 (17%)	16 (70%)	3 (13%)	0.080
11	no	20 (80%)		8 (40%)	7 (35%)	5 (25%)	
12	yes	16 (64%)	**<0.001**	4 (25%)	5 (31%)	7 (44%)	**0.001**
12	no	2 (8.0%)		1 (50%)	0 (0%)	1 (50%)	
13	yes	20 (80%)	>0.99	6 (30%)	10 (50%)	4 (20%)	0.77
13	no	20 (80%)		7 (35%)	7 (35%)	6 (30%)	
14	yes	10 (40%)	**0.018**	4 (40%)	3 (30%)	3 (30%)	0.050
14	no	2 (8.0%)		1 (50%)	1 (50%)	0 (0%)	
Total	yes	149 (41%)	**0.002**	53 (36%)	55 (37%)	41 (28%)	0.37
	no	110 (30%)		48 (44%)	33 (30%)	29 (26%)	

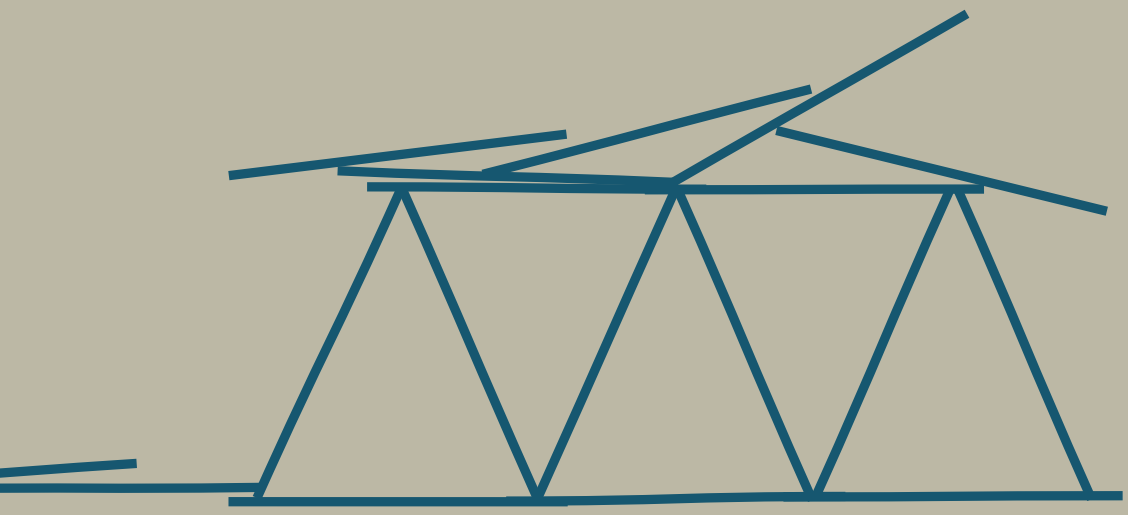
Bold indicates statistical significance, P < 0.05.

Appendix C. Multinomial logistic regression analysis of factors associated with the type of surgical treatment.

Comparison	Tenodesis vs. Scapholunate ligament repair			Capsulodesis vs. Scapholunate ligament repair		
	Relative Risk Ratio (95% Confidence Interval)	**Standard Error**	***P*-value**	**Relative Risk Ratio (95% Confidence Interval)**	**Standard Error**	***P*-value**
Midcarpal view						
Absent	*reference value*			*reference value*		
Present	2.6 (1.3 to 5.3)	0.93	**0.006**	2.0 (0.99 to 4.1)	0.73	0.053
Continent						
United States	*reference value*			*reference value*		
Other	4.2 (2.1 to 8.3)	1.5	**<0.001**	3.0 (1.5 to 6.1)	1.1	**0.002**
Years of experience						
0 to 5	*reference value*			*reference value*		
6 to 10	2.1 (0.84 to 5.4)	1.0	0.11	1.4 (0.54 to 3.9)	0.72	0.46
11 to 20	3.6 (1.4 to 9.6)	1.8	**0.008**	3.3 (1.2 to 8.6)	1.6	**0.018**
>20	3.2 (1.1 to 9.5)	1.8	**0.034**	1.6 (0.49 to 5.4)	1.0	0.42
Supervising						
No	*reference value*			*reference value*		
Yes	0.40 (0.15 to 1.0)	0.19	0.059	0.33 (0.12 to 0.87)	0.16	**0.026**
Subspecialty						
Hand and wrist	*reference value*			*reference value*		
Other	0.24 (0.11 to 0.53)	0.098	**0.001**	0.21 (0.085 to 0.51)	0.095	**0.001**

Bold indicates statistical significance, $P < 0.05$.

6 Factors Associated with the Quality of Online Information about Scapholunate Interosseous Ligament Insufficiency.



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Abstract

Background:
The Internet is increasingly used by patients to seek health information about their medical conditions. The online information is of variable quality, often difficult to read, and sometimes inaccurate or misleading. This study assessed factors associated with the quality, readability, and dominant tones of online information about scapholunate interosseous ligament (SLIL) insufficiency.

Methods:
Using the three most used search engines, we entered the terms "wrist sprain," "scapholunate ligament injury," and "SL dissociation" and assessed the quality of the 45 Web sites identified using the DISCERN tool, readability by the Flesch Reading Ease Score, the Flesch–Kincaid Grade Level, the Gunning Fog Index, and the Simple Measure Of Gobbledygook, and dominant tones using the IBM Watson Tone Analyzer and the Linguistic Inquiry and Word Count.

Results:
Online information about SLIL injuries had a mean DISCERN score of 39 ± 8.2. A dominant Web site tone of "sadness" correlated with lower DISCERN scores. A dominant tentative tone in text was associated with easier to comprehend texts.

Conclusion:
The online information regarding SLIL insufficiency is of generally low quality, limited readability, and the underlying tones may be misleading. Professional societies might consider efforts to provide appealing, readable, information about SLIL insufficiency and other less common diagnoses on the Internet.

Introduction

Rupture of the scapholunate (SL) interosseous ligament (SLIL) is one of the most common causes of traumatic disruptions of carpal kinematics.[1] The altered kinematics make the wrist vulnerable to a specific pattern of osteoarthritis known as SL advanced collapse (SLAC).[2–5] Several operations for SLIL injury are offered to reduce painful clicking and to delay arthritis by attempting to improve carpal alignment, for example, ligament repair or reconstruction, capsulodesis, or tenodesis. [6–9] Operative treatment has inconsistent results for improving carpal malalignment, stiffens the wrist, introduces operative risks such as infection and errant implant does not clearly improve symptoms better than sham surgery or alternative management strategies, and may not alter the natural history of SLAC.[10,11] The many areas of debate in the diagnosis and optimal treatment of SL ligament instability create complicated treatment decisions for patients and difficult discussions for the clinicians that care for them.

Accurate and trustworthy health information can help patients make decisions based on their values and not on misconceptions. The Internet is one of the most common places people seek health information.[12] Online information has variable quality of content, can be difficult to read, and are often inaccurate or misleading[13]. Prior studies that analyzed carpal tunnel syndrome[14] and distal radius fracture[15] on Web sites report low value and poor quality information and exceed the recommended sixth grade reading level.[16] The online available information for less common problems such as SLIL insufficiency might be even more problematic.

It can be helpful for clinicians to know what patients read online so that they can understand the influences on patient explanatory model and be prepared to address misconceptions. Little is known about the quality of online information regarding SLIL insufficiency. This study tested the hypothesis that there are no factors independently associated with SLIL insufficiency in online information content quality, measured using the DISCERN instrument[17]. Additionally, we assessed factors associated with readability of text, measured using the Simple Measure Of Gobbledygook (SMOG), and present dominant tones in text, measured using the IBMWatson Tone Analyzer.

Materials and methods

Data source

This study is exempt from Institutional Review Board approval. On December 18, 2017, we entered the terms "wrist sprain," "scapholunate ligament injury," and "SL dissociation" into three of the most used search engines (Google, Yahoo!, and Bing).[18] We cleared search history and cookies and searched with the browser in privacy mode to assure prior searches did not influence our results. Only 7% of online health information seekers leave the first result page.[19] To obtain enough Web sites, we included all first 40 hits of each search engine, resulting in 360 potential eligible Web sites. After excluding duplicates (n = 141) and irrelevant Web sites (n = 174, e.g., unrelated to the disease, research journals, Web-shops, videos, etc.), 45 Web sites remained for further analyses.

Measurements

We recorded whether Web sites were for profit (commercial or from private physician clinics) or nonprofit (affiliated with a university or academic center, government-funded, or from nonprofit organizations), treatment options that were discussed (operative, nonoperative, both, or none), and if there was a bias in favor of a specific treatment.

Additionally, we assessed if Web sites were certified with a Health On the Net (HON) code provided by the HON Foundation.[20] When Web sites meet their 8 principles (authority, complementarity, confidentiality, attribution, justifiability, transparency, financial disclosure, and advertising), a HON code seal on the Web page is accredited.[20] If this seal was not found on the original Web site, the HON code online database was consulted.[21]

The quality of online information content was evaluated using the DISCERN instrument.[17] The DISCERN instrument is a validated questionnaire designed to assess the quality of written health information for patients (Supplementary Table S1). It consists of 16 questions, 8 on reliability of the publication, 7 on quality of treatment information and 1 on overall rating. Each question is rated on a 5-point Likert scale ranging from 1 "no" to 5 "yes". Total scores range from 0 to 80 with higher scores indicating greater overall Web site quality.

Readability was assessed using four validated and often used tools: the Flesch Reading Ease Score (FRES)[22], the Flesch Kincaid Grade Level (FKGL)[23], the Gunning Fog Index (GFI)[24] and the Simple Measure Of Gobbledygook (SMOG)[25] (Supplementary Table S2]. We used a free online calculator to determine all readability ratings.[26] The FRES score ranges from 0 to 100, with higher scores indicating that a text is easier to comprehend. The FKGL reflects the required

Table 1. Web Site characteristics

Variables	Values
Websites	45
HON-code, n (%)	6 (13)
Non-profit, n (%)	20 (44)
Treatment options discussed, n (%)	
None	2 (4.4)
Only nonoperative treatment	1 (2.2)
Only operative treatment	5 (11)
Both treatments	37 (82)
Clear preference for treatment, n (%)	
None	43 (96)
Nonoperative treatment	1 (2)
Operative treatment	1 (2)
DISCERN	39 ± 8.2
Readability scores	
FRES	53 ± 12
FKGL	10 ± 2.5
GFI	14 ± 2.7
SMOG	10 ± 1.9
IBM domintant tones	
Fear	0.51 ± 0.012
Joy	0.53 ± 0.36
Sadness	0.61 ± 0.043
Analytical	0.67 ± 0.12
Tentative	0.82 ± 0.10
LIWC	
Self-references	0.13 ± 0.22
Social words	3.1 ± 2.9
Positive emotion	1.2 ± 0.48
Negative emotion	2.3 ±1.1
Overall cognitive words	4.5 ± 1.6
Articles (a,an,the)	11 ± 2.4
Big words	26 ± 4.3

Continuous variables as mean (±standard deviation); discrete variables as number (percentage). HON: Health On the Net code, FRES: Flesch Reading Ease Score, FKGL: Flesch-Kincaid Grade Level, GFI: Gunning Fog Index, SMOG: Simple Measure of Gobbledygook. LIWC: Linguistic Inquiry and Word Count.

U.S. grade level to read and understand text. Scores range from 3 to 12 and lower scores indicate that text is easier to read. The GFI gauges how many years of formal education is required to understand text with scores ranging from 0 to 15. The SMOG reflects how many years of education (ranging from 4 to 18) a person needs to understand a text. This readability tool is considered to be preferable in the biomedical field.[27,28] For this reason we only used the SMOG tool for bivariate and multivariate analysis. Since readability tools rely on word and sentence count, we formatted all website texts prior to analyses to avoid any under- or overestimation of readability levels. We removed headings, sentence fragments, references, lists with bullets and periods that did not mark the end of a sentence. Website texts were copied and pasted in Microsoft Word (Microsoft Corp., Redmond, WA).

We used the IBM Watson Tone Analyzer[29] and the Linguistic Inquiry and Word Count (LIWC)[30] to assess dominant tones in text. The IBM Watson Tone Analyzer measures dominant tones in written texts (emotion, language style and social tendencies) with scores from 0 to 1.0. Tones with a score of < 0.5 are considered to be "unlikely present" in the text. Scores > 0.75 are considered to be "very likely present" in text. We copied text from Web sites into the tone analyzer to measure present tones of the Web site. The LIWC is a lexicon-based validated tool that gauges language used in text.[30] It reflects the percentage of words in text that can be categorized into one of the following categories: basic linguistic like articles, big words (words with more than 6 letters), and on psychological level like self-references, social words, positive emotion, negative emotion, and overall cognitive words.

Reliability

One reviewer rated all Web sites on DISCERN. A recent study conducted by the same research team showed almost perfect intraobserver reliability of the DISCERN tool, with intraclass correlation coefficients of 0.95 (confidence interval [CI] = 0.92–0.96; $p \leq 0.001$).[31]

In this same study, the interobserver reliability for DISCERN, measured by intraclass correlation, was 0.95 (CI = 0.91–0.98; $p \leq 0.001$).

The IBM Watson Tone Analyzer was developed to compare tones in customer service conversations. IBM trained a machine-learning model based on a data set that was built on 96,000 customer conversations and the tone was rated by five trained annotators.[32] IBM states to achieve high accuracy when they compare their machine model to a benchmark data set, but they do not give actual numbers about reliability.[32] The LIWC showed high internal reliability scores for social processes (Crohnbach's $\alpha = 0.97$) affective processes (Crohnbach's $\alpha = 0.97$) cognitive processes (Crohnbach's $\alpha = 0.97$) when written essays were rated by LIWC as well as independent judges.[33]

Statistical analysis

Continuous variables are reported as mean and standard deviation and categorical variables as number and percentage. To compare continuous and dichotomous variables, we used Student's t-test, for two continuous variables we used Pearson's correlation, and analysis of variance test was used to compare continuous and ordinal variables. We indented to create three multivariable regression models to identify factors associated with (1) online information content quality measured using DISCERN, (2) readability measured using SMOG, and (3) very likely present dominant tones in text measured using the IBM Watson Tone Analyzer. A priori power analysis indicated that a sample size of 65 Web sites would provide 80% statistical power, with $\alpha = 0.05$, for a regression with 7 independent variables our complete model would account for 20% of the overall variability in quality, and a single variable would account for 10% or more of the variability in quality.

We could only include 45 Web sites and because of this lack of statistical power we did not perform multivariable analysis as this could result in unreliable findings.

Website characteristics

Of the 45 Web sites, 6 (13%) were HON code certified, 20 (44%) Web sites were non-profit, 37 (82%) discussed both treatment options (operative and nonoperative), and 43 (96%) had no clear preference for treatment (Table 1). The mean DISCERN score was 39 ± 8.2. Of all websites, 19 had a DISCERN score of ≥40 and 6 websites of >50. Mean readability score for FRES was 53 ± 12 (indicating "fairly difficult to read"), FKGL 10 ± 2.5, GFI 14 ± 2.7 and for SMOG 10 ± 1.9. Four websites were written below 7th grade level and required 7 years of education according to all readability tools. No website scored below 6th grade on all four readability tools. Tentative was the only very likely present dominant tone in text (0.82 ± 0.10). Mean LIWC score for negative emotions was 2.3 ± 1.1 and for positive emotions 1.2 ± 0.48.

Results

Discern

In bivariate analyses, a dominant website tone of sadness was the solely significant factor associated with DISCERN scores (r =-0.40, p = 0.0072) (Table 2). Websites containing a HONcode scored slightly greater on DISCERN (42 ± 5.5 p = 0.27) than websites without a HONcode (38 ± 8.5 p = 0.27), but this was not significant. Readability scores on GFI (r =- 0.25, p = 0.10) and SMOG (r =- 0.25, p = 0.10) were negatively but not significant correlated with DISCERN. No multivariable analysis was performed due to our small sample size and a lack of more than one significant factor.

Tabel 2 Bivariate analyses

Variables	DISCERN	P-Value	SMOG	P-Value	Tentative tone	P-Value
DISCERN	-	-	-0.25	0.10	-0.099	0.53
HON-code						
Yes	42 ± 5.5	0.27	8.9 ± 2.0	0.072	0.88 ± 0.043	0.17
No	38 ± 8.5		10 ± 1.8		0.81 ± 0.11	
Non-profit						
Yes	41 ± 9.3	0.13	10 ± 2.1	0.090	0.85 ± 0.098	0.10
No	37 ± 6.9		11 ± 1.5		0.80 ± 0.099	
Treatment options discussed						
None	27 ± 4.9	0.11	12 ± 0.07	0.065	0.79 ± 0.0	**0.0016**
Only nonoperative teatment	33 ± 0.0		13 ± 0.0		0.74 ± 0.0	
Only operative treatment	44 ± 13		11 ± 2.1		0.66 ± 0.097	
Both treatments	39 ± 7.2		9.9 ± 1.8		0.85 ± 0.086	
Clear preference for treatment						
None	39 ± 8.3	0.52	10 ± 1.9	0.34	0.82 ± 0.10	0.70
Nonoperative treatment	33 ± 0.0		13 ± 0.0		0.74 ± 0.0	
Operative treatment	31 ± 0.0		10 ± 0.0		0.85 ± 0.0	
Readability scores (r)						
FRES	0.15	0.31	-0.95	**<0.001**	0.47	**0.0015**
FKGL	-0.19	0.21	0.98	**<0.001**	-0.42	**0.0051**
GFI	-0.25	0.10	0.99	**<0.001**	-0.42	**0.0060**
SMOG	-0.25	0.10	-	-	-0.44	**0.0034**
IBM watson tone analyzer (r)						
Fear	0.064	0.96	1.0	**0.015**	-0.61	0.58
Joy	0.0086	0.99	0.23	0.61	-0.39	0.51
Sadness	-0.40	**0.0072**	0.042	0.79	-0.031	0.85
Analytical	-0.058	0.75	0.16	0.36	-0.0045	0.98
Tentative	-0.099	0.53	-0.44	**0.0034**	-	-

Variables	DISCERN	P-Value	SMOG	P-Value	Tentative tone	P-Value
LIWC						
Self-references	-0.0095	0.95	-0.16	0.30	-0.14	0.38
Social words	0.20	0.18	0.61	**<0.001**	0.28	0.074
Positive emotion	0.19	0.22	-0.034	0.83	0.14	0.39
Negative emotion	0.031	0.84	-0.25	0.094	0.25	0.11
Overall cognitive words	0.057	0.71	-0.33	**0.028**	0.23	0.15
Articles (a,an,the)	-0.18	0.23	0.40	**0.0072**	-0.29	0.06
Big words	-0.080	0.60	0.77	**<0.001**	-0.36	**0.019**

Pearson correlation indicated by *r*; **bold** indicates statistically significant difference; HON: Health On the Net code; FRES: Flesch Reading Ease Score; FKGL: Flesch-Kincaid Grade Level; GFI: Gunning Fog Index; SMOG: Simple Measure of Gobbledygook; LIWC: Linguistic Inquiry and Word Count.

Readability

SMOG scores were negatively correlated with the FRES (r = -0.95, $p \leq 0.001$) and positively correlated with FKGL (r = 0.98, $p \leq 0.001$), and GFI (r = 0.99, $p \leq 0.001$) scores. A dominant tone of "fear" (r = 1.0, p = 0.015) and "tentative" (r = -0.44, p = 0.0034), the use of social words (r = 0.61, $p \leq 0.001$), cognitive words (r= -0.33, p = 0.028), articles used (r = 0.40, p = 0.0072) and big words (r = 0.77, $p \leq 0.001$) were factors associated with the SMOG.

Dominant tones

Dominant tentative tone in text was associated with easier readability levels (FRES (r = 0.47, p = 0.0015), FKGL (r = -0.042, p = 0.0051), GFI (r = -0.42, p = 0.0051) SMOG (r = -0.44, p = 0.0034) and use of big words (r = -0.36, p = 0.019).

Discussion

Patients increasingly search the Internet to obtain health information, but website texts can be misleading, of low quality, and sometimes inaccurate.[12,34] This study assessed factors associated with the quality of online information content regarding SLIL measured using the DISCERN instrument. Additionally, we assessed factors associated with readability levels, measured using SMOG, and present dominant tones in texts measured using the IBM Watson Tone Analyzer.

Our study has several limitations. First, besides a broad search with use of different search terms only 45 websites met our inclusion criteria. We could not include enough websites that addressed SLIL insufficiency to reach adequate power according to a priori power analysis. Among the excluded websites, 45% were peer-reviewed publications and 29% were written for health care professionals e.g. summaries for radiologist, and presentation sheets. Second, we evaluated websites written in English that were available on the day of our search, December 18th, 2017. The findings of this study may not be reproducible within the next few years. Third, our search contained three terms but patients might use other terms, find other Web sites, and read other information than included in our study. Fourth, although DISCERN is a validated tool with specific rating criteria, it partly relays on subjective input. Fifth, readability tools are based on word and sentence count only. They do not account for website structure, layout, or illustrations – items that can enhance understanding.

The finding that a dominant tone of sadness was the only factor associated with DISCERN scores might be a result of the small sample size, and relative dearth of information regarding SLIL insufficiency on the Internet. If the existing information reinforces sadness rather than emphasizing adaptiveness, this material may do harm.

The finding that the SMOG tool was associated with the FRES, FKGL and GFI shows the very strong correlation among all readability tools although they use different formulas and scales. A dominant tone of fear correlated with difficult to read texts, a dominant tentative tone with easier texts. It shows that there is variation among websites in word choice and concepts which can affect illness beliefs, symptom intensity, and magnitude of limitations. Additionally, we found that most websites were above the recommended reading levels. None of the websites addressing SL insufficiency met standards for readability with fewer than 6 years of education on all readability tools as advised by the National Institution of Health and The American Medical Association. This increases the risk of misunderstandings and misconceptions if information is too difficult to read or comprehend.

We found that a tentative tone was more likely present in websites that were easier to read. It shows that if websites use easier words they present their information in another way than more difficult websites. Word choice and emotional texts could influence a patients' attitude and expectations towards an illness or treatments. However, little is known about the influence of sentiments in online information. Some recent studies in other medical fields than musculoskeletal illnesses assessed sentiments in online text.[35–37] A study about online cancer screening information found that colonoscopy information had a greater prevalence of negative sentiments than mammography.[36] Another study about Zika virus images on social media found that many images contained negative sentiments and induced fear.[37] Understanding dominant and present sentiments in information can give a useful insight in patients attitudes and expectations towards disease and treatment.

Less common diseases and illnesses may be at a greater risk for limited and lower quality information on the internet. Professional societies might consider putting effort to provide appealing, readable, information about less common problems such as SLIL insufficiency on the Internet.

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Supplementary Table S1 DISCERN questionnaire

Section 1: is the publication reliable?	
Q1	Are the aims clear?
Q2	Does it achieve it aims?
Q3	Is it relevant?
Q4	Is it clear what sources of information were used to compile the publication (other than the author or producer)?
Q5	Is it clear when the information used or reported in the publication was produced?
Q6	Is it balanced and unbiased?
Q7	Does it provde details of additional sources of support and information?
Q8	Does it refer to areas of uncertainty?
Section 2: How good is the quality of information on treatment choice?	
Q9	Does it describe how each treatment works?
Q10	Does it describe the benefits of each treatment?
Q11	Does it describe the risks of each treatment?
Q12	Does it describe what would happen if no treatment is used?
Q13	Does it describe how the treatment choices affect overall quality of life?
Q14	Is it clear that there may be more than one possible treatment choice?
Q15	Does it provide support for shared decision making?
Section 3: Overall rating of the publication	
Q16	On the basis of the answers to all of the above questions, rate the overall quality of the publication as a source of information about treatment choices

For section 1 and 2 No: give 1 point, Partially: give 2,3 or 4 points. Yes give 5 points. For section 3 Low: give 1 point, intermediate: give 2,3 or 4 points. High: give 5 points.

Supplementary Table S2 Readability formulas

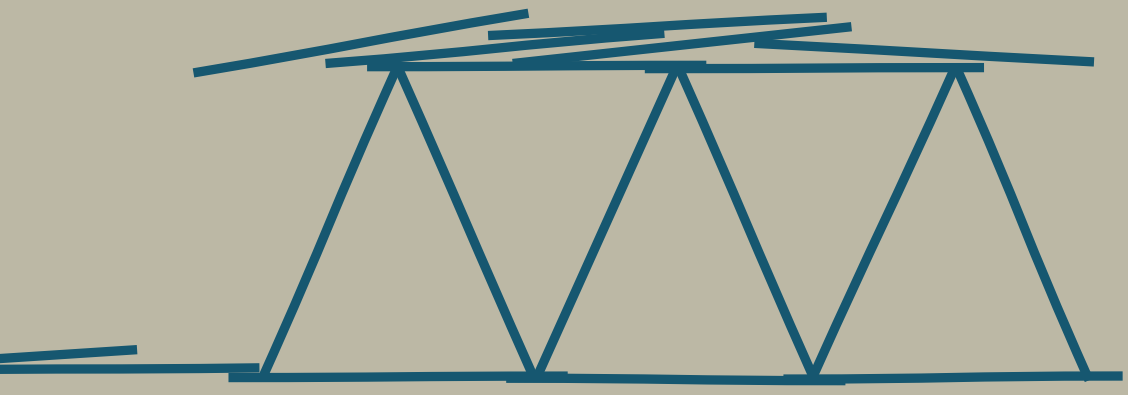
FRES	206.835 – (1.015 x average sentence length) – (84.6 x syllables/word)
FKGL	(0.39 x average sentence length) + (11.8 x syllables/word) – 15.59
GFI	0.4 (average sentence length + 100(no. of polysyllable words/no. words))
SMOG	3.1291 + 1.043√(30 x no. of polysyllable words/no. of sentences)

FRES: Flesch Reading Ease Score, FKGL: Flesch-Kincaid Grade Level, GFI: Gunning Fog Index, SMOG: Simple Measure of Gobbledygook.

Part III

Treatment of scapholunate ligament injuries.

7 Optimizing recovery after scapholunate ligament surgery: similar results following short and long immobilization, a systematic review.



HAND, American Volume, Submitted

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Abstract

Scapholunate ligament (SL) injuries can lead to pain and abnormal carpal kinematics and, if needed, can be treated surgically. This systematic review aims to provide an overview of postoperative immobilization protocols for surgically treated scapholunate ligament injuries and to assess their impact on patient-reported outcomes.

A systematic literature search was conducted following the PRISMA guidelines. Studies with at least six weeks follow-up, clear descriptions of the intervention, postoperative rehabilitation details, and validated patient-reported outcomes (PROMs) were included. Methodological quality was assessed using the 'methodological index for non-randomized studies' method, and data on study characteristics, intervention, postoperative immobilization, PROMs, pain, range of motion, grip strength, and complications were extracted.

Fifteen studies involving 533 patients were included. Most patients (82%) underwent tenodesis, 18% underwent capsulodesis. Immobilization varied from 2 to 8 weeks. No differences were observed between short (≤6 weeks) and long (>6 weeks) immobilization in terms of PROMs, pain, range of motion, grip strength, or complications.

This review suggests that short and longer immobilization periods after surgery might yield similar outcomes in terms of PROMs, pain, range of motion, grip strength, and complications. Early active motion after surgery may be safe, potentially offering improved patient comfort, quicker return to activities and saving costs.

Introduction

Scapholunate ligament (SL) injuries can occur after a traumatic fall which may result in ligament tears followed by abnormal carpal kinematics.[1] Complete tears of the SL might lead to pain due to dysfunction or osteoarthritis.[2] To treat pain and SL dysfunction, non-surgical treatment regimens like taping, physiotherapy, analgesics, immobilization and injections have been reported.[3]

If non-surgical treatment is unsuccessful, surgical treatment like capsulodesis or tenodesis techniques for chronic SL ligament dysfunction might be offered.[4–7] Capsulodesis techniques aim to prevent flexion of the scaphoid and dorsiflexion of the lunate. Tenodesis techniques aim to restore wrist kinematics by the use of tendon graft.[8–10]

A systematic review reported improved postoperative radiographic measurements, pain and patient reported outcome measurements (PROMs) after capsulodesis and tenodesis.[11] However, surgery resulted in significant decreases of wrist flexion and extension. This was in line with another review, which reported a similar significant decrease in wrist flexion.[12] Additionally, this review mentioned different periods of immobilization ranging from four up to ten weeks. No further information about the used rehabilitation protocols, or a comparison between long or shorter immobilization was made.

To improve rehabilitation after SL surgery this information is valuable. Prolonged immobilization might alter the mechanical properties of ligament- or tendon grafts, which might result in a stiff wrist and a reduction in range of motion. Contrary, short immobilization and early initiation of physiotherapy might harm the new reconstruction.

Theoretically, if shorter immobilization and early start of exercises does not lead to more complications or worse outcomes, it might yield more patient comfort, earlier return to activities and reduced costs. To start exploring this theory, an overview of the current used immobilization protocols is necessary.

Therefore, the primary objective of this systematic review is to describe and create an overview of different immobilization protocols reported in current literature for surgically treated scapholunate ligament injuries. Secondary, an overview of patient reported outcome measures, post-operative range of motion, pain, strength, and complications regarding short and longer immobilization will be presented.

Materials and methods

This systematic review followed the PRISMA statement reporting guideline.[13] A search was performed and updated in august, 2023. The databases Embase, Medline ALL Ovid, Web of Science Core Collection, Cochrane Central Register of Controlled Trials were explored by an independent data analyst. References of the reviewed studies were scanned to identify potential eligible studies.

Eligibility criteria

Studies were considered eligible if: they concerned patients who underwent capsulodesis or tenodesis due to symptomatic scapholunate ligament injuries; described a comparison with at least one validated patient-reported outcome (PROM) before and after surgery; gave a specific description of the intervention used and had a follow up of at least 6 weeks; provided a description of the immobilization period; oncerned at least 5 adult humans, and was written in English.

Study selection

Two reviewers (DB and RO) independently performed a screening based on title and abstract. The remaining studies were assessed for eligibility by both reviewers. Disagreement was discussed and resolved by consensus. If no agreement was obtained a third reviewer (GK) was consulted.

Data items

Data on study design, patient demographics, intervention characteristics, post-operative immobilization, and details about the range of motion, grip strength and complications were extracted. The primary outcome was the difference in reported PROMs and pain before and after surgery. Secondary outcomes were range of motion, grip strength and complications.

Study risk of bias assessment

To assess the methodological quality of the included studies the methodological index for non-randomized studies (MINORS method) was used.[14] The MINORS method involves an eight item questionnaire for non-comparative studies, and additional four items for comparative studies. The items were scored 0 (not reported), 1 (reported but inadequate) or 2 (reported and adequate). Non-comparative studies were considered of moderate quality if the total score was between 9-14, comparative studies were considered moderate quality with a score between 15 and 22.

Analysis

Because no randomized controlled trials were included, and therefore a high risk for heterogeneity and sensitivity to bias exists, the results were narratively reported. PROMS were reported as relative improvement at maximum follow up time, compared to pre-operative PROMS. The included studies used the Patient-Rated Wrist Evaluation (PRWHE), Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire and QuickDASH questionnaire.

The PRWHE is a questionnaire in which patients can rate the level of pain and disability.[15] A total score of 0 indicates no pain and functional impairment, a total score of 100 indicates worst possible pain and function.

The DASH is a 30 item questionnaire subdivided in symptoms and limitation in activities.[16] The higher the score (0-100) the more impairment the patient experiences. A smaller sub derived questionnaire (QuickDASH) consists of 11 questions and results to the amount of impairment the patient experiences on a 0-100 scale. [17]

For pain the Visual Analogue Scale (VAS) was used. The VAS is a questionnaire that reflects the sensation of pain on a 0 to 10-point scale, where 0 is no pain and 10 is excruciating pain.

To compare outcome between different PROMS used in literature, the minimal clinically important difference (MCID) was used. The MCID is considered to be the smallest difference in an outcome measure that is perceived by the patient to be important.[18] As no MCID has been examined in patients with scapholunate injuries, earlier reported MCID's for upper extremity injuries were held as threshold. For PRWHE; 11.5, DASH; 15 and quickDASH; 8, were regarded as minimum clinically important difference. [19,20]

The immobilization periods were subdivided in a short (≤6 weeks) and longer immobilization (>6 weeks) period. The wrist was considered immobilized if the scapholunate / scaphocapitate joint was fixated with a K-wire or screw, or if no K-wire was used, a non-removable splint or cast was applied.

Complications were classified according to the Clavien classification for post-operative complications ranging from Grade I, which includes any deviation from the normal postoperative course without the need for pharmacological treatment to Grade III requiring surgical intervention. [21]

Results

Fifteen studies were eligible resulting in the inclusion of 533 patients with a mean age per study ranging from 27 to 47 years (Figure 1). Ninety-five patients (18%) were treated using a capsulodesis technique, and 438 patients (82%) were treated using a tenodesis technique (Table 1). Follow up after capsulodesis ranged from 16 to 97 months, and after tenodesis 12 to 40 months. Mean overall follow up was 2.5 years. Reported duration of immobilization ranged from 1 week to 8 weeks. Of all studies, ten were considered of moderate quality, and five of poor quality (Figure 2).

Ten studies reported tenodesis techniques [22–30] and five studies capsulodesis techniques. [31–34] Most studies reported the 3-ligament tenodesis (3-LT) as proposed by Garcia Elias.[35] Two studies compared 3-LT results with a scapholunate intercarpal ligamentoplasty procedure and a 4-bone tendon weave repair [22,28]. Results after SLAM technique[24], 360° tenodesis[26], extensor carpi radialis longus tenodesis[27] and scapholunotriquetral tenodesis[30] were reported. The blatt procedure[31], mayo[32], Berger[33,34] and Viegas capsulodesis[33] techniques were also reported.

Figure 1, identification of studies via databases and registers.

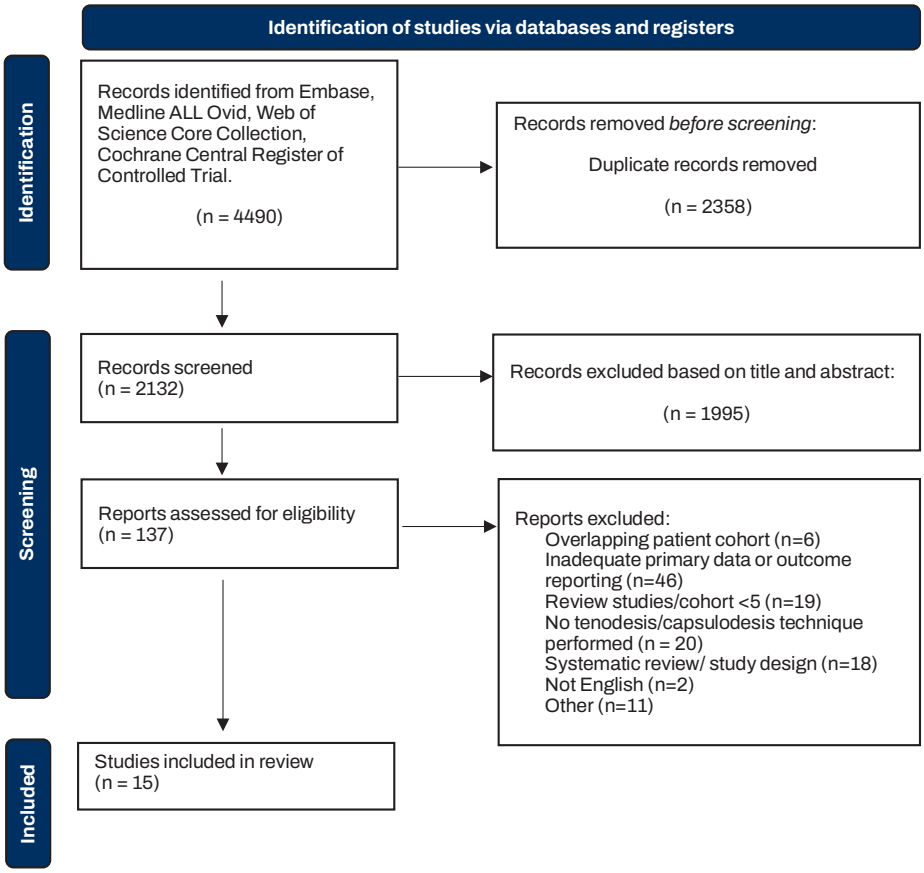

Figure 2, methodological quality of the included studies according to the MINORS method.

Study	1. A clearly stated aim	2. Inclusion of consecutive patients	3. Prospective collection of data	4. Endpoints appropriate to the aim of the study	5. Unbiased assessment of the study endpoint	6. Follow-up period appropriate to the aim of the study	7. Loss to follow up less than 5%	8. Prospective calculation of the study size	9. An adequate control group	10. Contemporary groups	11. Baseline equivalence of groups	12. Adequate statistical analyses	**Total score**
Athlani, L., et al.	2	1	1	2	2	1	2	0	2	1	1	1	16
Blackburn, J., et al.	2	2	2	2	2	1	2	0					13
Dolderer, J. H., et al.	1	2	2	2	1	1	2	0					11
Elgammal, A. and B. Lukas	1	2	1	2	1	1	2	0					10
Kakar, S., et al.	2	1	0	2	1	1	2	0					9
Kaltenborn, A., et al.	2	2	2	2	2	1	1	0					12
Kemler, M.A., et al.	1	1	2	1	0	1	0	0	0	0	1	0	7
Links, A. C., et al.	2	1	0	2	1	2	0	1	2	1	1	1	14
Pauchard, N., et al.	2	1	2	1	1	1	0	0					8
Ross, M., et al.	0	2	2	2	1	1	0	0					8
Konduru, R. S., et al.	2	2	1	2	1	1	1	0					10
Luchetti, R., et al.	2	2	2	2	2	1	1	0					12
Rosa, N. D., et al.	2	2	0	2	2	1	0	0	2	1	2	2	16
Shibayama, H., et al.	2	1	1	2	1	2	1	0					10
Yang, Y., et al.	2	2	0	2	1	1	0	0					8

Figure 2

Immobilization protocols

Various periods of immobilization were reported ranging from 1 to 24 weeks for tenodesis techniques, whereas for capsulodesis, immobilization periods between 4 to 12 weeks were documented. All authors reported the use of different casts, splints, or combinations (Table 1).

K-wires were used in 11 studies. Four studies performed a procedure without the use of k-wires [36–39], one study compared a procedure with k-wires to a procedure without. One study used a cannulated screw to maintain reduction between the scaphoid an lunate, which was removed 3 to 6 months after surgery.

Five studies [23,24,26,27,40] reported a start of physiotherapy within 6 weeks after tenodesis of which two allowed movement after one week[23,40] or immediate [30] movement. Eight studies started physiotherapy after at least six weeks of immobilization.

After capsulodesis, two studies[31,41] reported a start of physiotherapy at 4-6 weeks after surgery and three studies[32–34] reported a start at 8 to 12 weeks. The aims and permitted movements during physiotherapy were described in only two studies. [26,30]

Patient related outcome

All studies reported improvement of PROM which exceeded the MCID regardless type of surgery or duration of immobilization (Table 2). VAS after tenodesis ranged from 1 to 6. VAS scores for short immobilization after capsulodesis improved by 3 points, long immobilization improved VAS by 5 points in one study.

Table 1. Characteristics of the included studies

	Study	Year	study design	Type	Procedure	Patients (no.)	Mean age (years)	Follow up (months)
1	Athlani, L., et al.	2019	RC	Tenodesis	3LT	20	43	28
				Tenodesis	SLICL	26	44	36
2	Blackburn, J., et al.	2020	RC	Tenodesis	3LT	203	47	12
3	Dolderer, J. H., et al.	2019	PC	Tenodesis	SLAM	22	47	12
4	Elgammal, A. and B. Lukas	2016	RC	Tenodesis	3LT	20	43	24
5	Kakar, S., et al.	2021	RC	Tenodesis	360 procedure	9	45	40
6	Kaltenborn, A., et al.	2017	PC	Tenodesis	ECRL tenodesis	46	29	24
7	Kemler, M.A., et al.	2022	PC	Tenodesis	3LT	11	43	12
				Tenodesis	3LT, Internal brace	10	42	12
8	Links, A. C., et al.	2008	RC	Tenodesis	3LT + RASL	21	30	29
				Tenodesis	4-bone tendon weave repair	23	29	29
9	Pauchard, N., et al.	2013	PC	Tenodesis	3LT	20	43	25
10	Ross, M., et al.	2013	PC	Tenodesis	SLT	11	36	14
11	Konduru, R. S., et al.	2006	CS	Capsulodesis	Blatt	20	37	41
12	Luchetti, R., et al.	2010	PC	Capsulodesis	Mayo	18	35	45
13	Rosa, N. D., et al.	2020	RC	Capsulodesis	Viegas	20	27	24
				Capsulodesis	Berger	20	35	48

RC = retrospective cohort; PC = prospective cohort; CS = case series.

duration immobilization (weeks)	Cast/split	K-wires	Physiotherapy
8	Fiberglass splint	Removed after 8 weeks	Start after 12 weeks, no heavy loads for 6 months
8	Fiberglass splint	Removed after 8 weeks	Start after 12 weeks, no heavy loads for 6 months
0-2	Cast	No k-wires	Start after 3-14 days with active mobilization. After 6 weeks strengthening
6	Cast	Removal not reported	Not reported
8	Thumb spica (2 weeks), followed by complete circular cast (6 weeks)	Removed after 8 weeks	Not reported
4-6	Short arm volar splint, followed short arm cast	No k-wires	Supervised hand therapy, dart throwers, ROM wrist propriocepsis and gradual strengthening
6	Forearm splint	No k-wires	Start after 6 weeks, intensified after 9 weeks No flexion > 40° for 9 weeks
6	Cast	Removed after 6 weeks	Start after 6 weeks
1	Short arm splint	no k-wires	Start after 1 week
12-24	Thumb spica splint (2 weeks), followed by a cast (6 weeks)	Screw removed after 12-24 weeks	Start after 8 weeks with ROM, strengthening at week 12
8	Cast	No k-wires	Start at 8 weeks with ROM, strengthening at week 12
8	Cast	Removed after 8 weeks	Start after 8 weeks
6-8	Wrist splint	removed after 6-8 weeks	Start immediately, to 30° flexion and extension. After k-wire removal intensified ROM and dart throwing.
4-6	Palmar slab, scaphoidtype plaster	No K-wires	Not reported
4	Palmar thermoplastic splint or fiber cast	Removed after 4 weeks	Start after 4 weeks, graded resistive hand/wrist training, forearm strengthening and propriocepsis
8	Cast	Removed after 8 weeks	Start after 8 weeks
8	Cast	Removed after 8 weeks	Start after 8 weeks

Table 2, Immobilization, and patient related outcome.

Study	Type	Immobilization	Patients	PRWHE (improvement)	(quick) DASH (improvement)	PROM > MCID	VAS (improvement)
Blackburn, J., et al.	T	≤ 6 weeks	203	31	NR	Yes	3
Dolderer, J. H., et al.	T	≤ 6 weeks	22	NR	30	Yes	1
Kakar, S., et al.	T	≤ 6 weeks	9	46	NR	Yes	6
Kaltenborn, A., et al.	T	≤ 6 weeks	46	NR	26	Yes	NR
Kemler, M.A., et al.	T	≤ 6 weeks	11	19	12	Yes	2
Kemler, M.A., et al.	T	> 6 weeks	10	15	5	Yes	2
Athlani, L., et al.	T	> 6 weeks	20	22	18	Yes	2
Athlani, L., et al.	T	> 6 weeks	26	39	40	Yes	4
Elgammal, A. and B. Lukas	T	> 6 weeks	20	NR	17	Yes	3
Links, A. C., et al.	T	> 6 weeks	21	NR	53	Yes	5
Links, A. C., et al.	T	> 6 weeks	23	NR	22	Yes	3
Pauchard, N., et al.	T	> 6 weeks	20	22	18	Yes	2
Ross, M., et al.	T	> 6 weeks	11	24	29	Yes	1
Konduru, R. S., et al.	C	≤ 6 weeks	20	48	NR	Yes	NR
Luchetti, R., et al.	C	≤ 6 weeks	18	NR	18	Yes	3
Shibayama, H., et al.	C	> 6 weeks	5	NR	22	Yes	NR
Rosa, N. D., et al.	C	> 6 weeks	20	31	NR	Yes	NR
Rosa, N. D., et al.	C	> 6 weeks	20	19	NR	Yes	NR
Yang, Y., et al.	C	> 6 weeks	12	NR	31	Yes	5

T = Tenodesis; C = Capsulodesis; NR = Not reported.

Range of motion and grip strength

Flexion ranged from 39° to 73° in the tenodesis group and 45° to 61° in the capsulodesis weeks group (Table 3). Extension after surgery ranged from 36° to 67° in the tenodesis group and 42° to 69° in the capsulodesis weeks group. Grip strength ranged from 20 to 70 in the tenodesis group and 23 to 33 in the capsulodesis group.

Complications

Ten studies reported complication rates below 10%, which consisted mostly of grade I complications (Table 4). One study reported a complication rate of 22% with half of these complications categorized as grade IIIb and IIIc.[27] This study had a short immobilization period. Another study reported a high complication rate of 60% with the majority falling into grade 1.[22] This study involved an immobilization period lasting longer than 6 weeks. Three studies did not report any information about complications.[24,34,41] One study excluded two patients who suffered traumatic failure of the reconstruction.[40]

Table 3, Range of motion and grip strength after surgery.

Study	Type	Immobilization	Patients	Flexion	Extension	Ulnar deviation	Radial deviation	Grip strength
Blackburn, J., et al.	T	≤ 6 weeks	203	48	60	28	18	NR
Dolderer, J. H., et al.	T	≤ 6 weeks	22	48	53	32	18	70
Kakar, S., et al.	T	≤ 6 weeks	9	56	47	39	14	39
Kaltenborn, A., et al.	T	≤ 6 weeks	46	66	56	36	13	30
Kemler, M.A., et al.	T	≤ 6 weeks	11	60	60	37	17	23
Kemler, M.A., et al.	T	> 6 weeks	10	73	67	46	32	20
Athlani, L., et al.	T	> 6 weeks	20	39	43	24	14	32
Athlani, L., et al.	T	> 6 weeks	26	57	56	32	16	40
Elgammal, A. and B. Lukas	T	> 6 weeks	20	41	54	31	19	43
Links, A. C., et al.	T	> 6 weeks	21	45	55	21	13	41
Links, A. C., et al.	T	> 6 weeks	23	27	36	21	14	34
Pauchard, N., et al.	T	> 6 weeks	20	39	43	24	14	30
Ross, M., et al.	T	> 6 weeks	11	NR	NR	NR	NR	44
Konduru, R. S., et al.	C	≤ 6 weeks	20	45	53	30	16	28
Luchetti, R., et al.	C	≤ 6 weeks	18	NR	NR	NR	NR	27
Shibayama, H., et al.	C	> 6 weeks	5	54	80	NR	NR	NR
Rosa, N. D., et al.	C	> 6 weeks	20	61	68	NR	NR	23
Rosa, N. D., et al.	C	> 6 weeks	20	59	69	NR	NR	25
Yang, Y., et al.	C	> 6 weeks	12	47	42	NR	NR	33

T = Tenodesis; C = Capsulodesis; NR = Not reported. Range of motion in °, grip strength in kg.

Table 4, Complications according to the Clavien classification for post-operative complications

Study	Type	Immobilization	Complication rate (%)	Grade I	Grade II	Grade IIIa	Grade IIIb	Grade IIIc
Blackburn, J., et al.	T	≤ 6 weeks	4%	6	2		5	
Dolderer, J. H., et al.	T	≤ 6 weeks	NR					
Kakar, S., et al.	T	≤ 6 weeks	0%					
Kaltenborn, A., et al.	T	≤ 6 weeks	22%	5			2	3
Kemler, M.A., et al.	T	≤ 6 weeks	9%					
Kemler, M.A., et al.	T	> 6 weeks	10%					
Athlani, L., et al.	T	> 6 weeks	8%					2
Athlani, L., et al.	T	> 6 weeks	60%	10			2	
Elgammal, A. and B. Lukas	T	> 6 weeks	6%	3			3	
Links, A. C., et al.	T	> 6 weeks	3%	3				
Links, A. C., et al.	T	> 6 weeks	0%					
Pauchard, N., et al.	T	> 6 weeks	8%	3			3	2
Ross, M., et al.	T	> 6 weeks	9%				1	
Konduru, R. S., et al.	C	≤ 6 weeks	6%	5			0	1
Luchetti, R., et al.	C	> 6 weeks	0%					
Shibayama, H., et al.	C	> 6 weeks	NR					
Rosa, N. D., et al.	C	> 6 weeks	0%					
Rosa, N. D., et al.	C	> 6 weeks	25%	5				
Yang, Y., et al.	C	> 6 weeks	NR					

T = Tenodesis; C = Capsulodesis

Discussion

This study presented an overview of the various immobilization protocols after surgery for scapholunate ligament injuries. In the context of tenodesis techniques, immobilization periods ranging from 1 to 24 weeks have been reported, whereas for capsulodesis, immobilization periods between 4 to 12 weeks are documented. Short and longer immobilization both result in an MCID improvement of the reported PROMS. This review found similar range of motion, grip strength and number of complications between both post-operative regimens.

This study has several limitations. It includes nonrandomized studies of moderate to poor quality, involving a wide range of performed procedures. Consequently, there is an elevated risk of bias. For this reason, we reported our results narratively. As bivariate analysis was not feasible, the current results do also not permit a subgroup analysis based on factors such as SL staging (grade), static/dynamic, time to surgery and method used to establish the diagnosis. Scapholunate ligament injuries should be considered a spectrum, and therefore information on gradation/severity of the injury is crucial for further research and analysis.

We considered it essential to report PROMs, especially in wrist pain. Consequently, a comparison over time (before and after surgery) with at least one validated PROM was an inclusion criterium. As a result, we excluded several studies which were important in understanding the effect of surgical interventions: those that did not mention PROMS at all [6,35,42], or did not report a comparison over time (before and after surgery).[9,43]

The results imply that tenodesis and capsulodesis techniques improve PROMs exceeding the MCID with low complication rates and without harming the reconstruction regardless of the duration of immobilization. These findings, are in line with previous research suggesting that starting non weight bearing motion two weeks after a 3-LT procedure is safe.[44] Moreover, two studies suggested that initiating hand therapy after only one week might be considered safe.[36,40] While the study performed by Kemler et al. [45] has a high risk of bias, both studies did not report an increase in number of complications following an early active motion protocol.

The use of k-wire ranged from no k-wires[36,39] to fixation for 8 weeks.[46,47] These differences reflect uncertainty about whether k-wires are needed and underscores the need for more research.

Postoperative ROM and grip strength seem similar with either short or long immobilization. However, it is important to note that the total follow up period was different between the studies and therefore should be interpreted with care. While

the ROM and grip strength might suggest that there is no difference between short and longer immobilization after surgery, it is not known when they become similar.

In our review we identified two studies with relatively high complication rates after tenodesis procedures. While most complications were categorized as low-grade complications (grade I), a complication rate of 22% and 60% can still be considered high. Specifically, Kaltenborn et al. (2017) reported a complication rate of 22% after short weeks of immobilization. Athlani et al. (2019) documented a complication rate of 60% initiating physiotherapy 3 months after surgery.[22,27] Given the differences in post-operative regimens utilized in both studies, the complication rates cannot be attributed to start mobilizing too fast.

In conclusion, the diversity in surgical procedures and post-operative immobilization protocols pose a challenge when attempting to analyze and improve treatment protocols but this review did not find differences between short immobilization (≤6 weeks) and longer immobilization (>6 weeks). Additionally, post-operative range of motion, pain, strength, and complications seem comparable.

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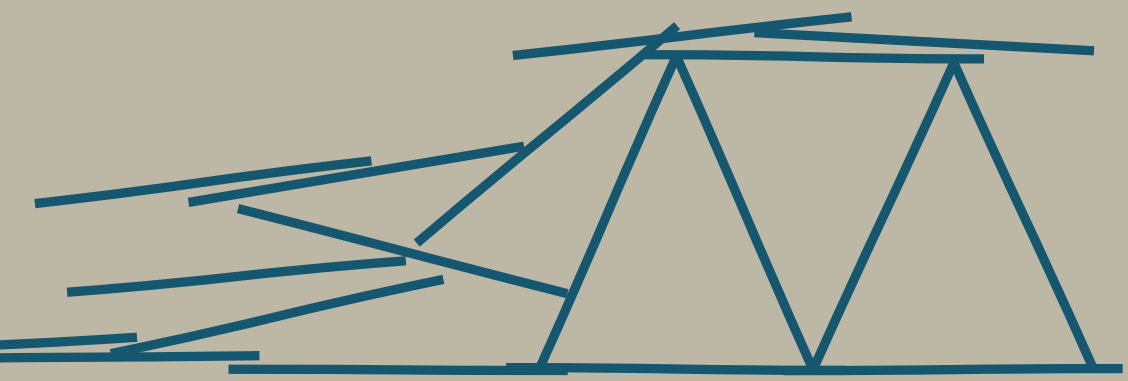
8 Is early active motion after three ligament tenodesis non-inferior to late active motion? A prospective multicenter cohort study.



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Abstract

Purpose:
If early active motion after 3-ligament tenodesis is safe, it may yield more patient comfort and an early return to activities. Therefore, the aim of this study was to investigate whether early active motion is noninferior to late active motion after 3-ligament tenodesis for scapholunate interosseous ligament injuries.

Methods:
This prospective, multicenter cohort study, using a noninferiority design with propensity score matching, compared a late active motion protocol (immobilization for 10-16 days, wrist therapy in weeks 5-6) with an early active motion protocol (immobilization for 3-5 days, wrist therapy during week 2). Patients who were older than 18 years, had complete baseline information on demographics, and underwent 3-ligament tenodesis were included. The outcome measures were postoperative Patient-Reported Wrist/Hand Evaluation scores, pain, complications, return to work, range of motion, grip strength, and satisfaction with treatment results at 3 months of follow-up.

Results:
After propensity matching, a total 108 of patients were included. PRWHE and pain during physical load following an early active motion protocol were non-inferior compared to a late active motion protocol. Furthermore, it did not lead to an increase of complications, differences in range of motion, grip strength or less satisfaction with the treatment result. Earlier return to work was not observed.

Conclusion:
Early active motion leads to non-inferior results without more complications. Based on these findings, early active motion can be considered safe, and might be recommended due to its potential benefits compared to late active motion after three ligament tenodesis.

Level of evidence:
Therapeutic, Level III

Introduction

Interactions between ligaments, tendons and the 8 carpal bones allow the wrist wide range of motion while maintaining stability. A traumatic fall onto an outstretched hand with the wrist in extension can lead to damaged ligaments and instability.[1] Injuries of the scapholunate interosseous ligament (SLIL) are the most frequently diagnosed cause of carpal instability.[2] SLIL injuries can result in painful carpal instability, limitations in activities, and progress into scapholunate advanced collapse.[3]

To treat pain, instability and possibly prevent progression into a scapholunate advanced collapse, numerous surgical methods have been proposed.[4–6] A commonly used technique to stabilize the SLIL is tenodesis. The use of the flexor carpi radialis tendon (FCR) was first described by Brunelli and Brunelli and has been modified by Garcia-Elias et al and van den Abbeele et al.[4,5,7] The so-called 3-ligament Tenodesis (3LT) is associated with improvement of hand function scores, reduction of pain and reduction of the gap between the scaphoid and lunate.[8,9]

According to the original surgical paper, the 3LT procedure is followed by immobilization in a cast for 6 weeks.[5] However, various immobilization periods have been reported in literature, varying from 2 to 8 weeks, and postoperative exercise protocols also vary greatly.[5,6,10–12] If shorter immobilization and early start of hand exercises does not lead to more complications or worse outcomes, it may yield more patient comfort and early return to activities.

Therefore, this prospective, multicenter cohort study investigated if an early active motion protocol is non-inferior compared to a late active motion protocol after a 3LT procedure in post-operative Patient Reported Wrist/Hand Evaluation (PRWHE). The study also evaluated differences in postoperative pain, ROM, grip strength, complications, return to work, and satisfaction with the treatment result.

Methods

Study design

We conducted a multicenter cohort study using a non-inferiority design with propensity score matching, following the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement.[13]

Setting

This study was approved by the Institutional Review Board of Erasmus Medical Center, Rotterdam, and all patients provided consent for their data to be used. This study was completed in accordance with the Helsinki Declaration, as revised in

2013. All patients were treated according to the surgical procedure as proposed by Garcia-Elias et al,[5] without K-wire fixation, in specialized centers for hand surgery and therapy (Xpert Clinics Hand- en polszorg and Xpert Handtherapie) with 18 outpatient clinics in The Netherlands.

Participants

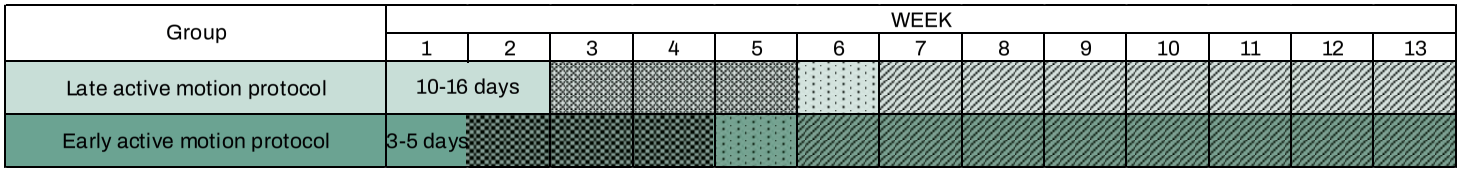
We included all patients older than 18 years with complete baseline information on demographics, who underwent 3LT in the period from January 2012 to April 2017 in the Xpert Clinic. The decision to proceed to surgical treatment was one shared by the patient and surgeon. This was based on the patient's history, physical examination, and additional imaging. In 2015, the standard postoperative regimen was changed to an early active motion protocol (Fig. 1) based on the rationale that shorter immobilization would lead to more patient comfort and an early return to activities. To ensure the correct postoperative regimen was followed and to limit possible unawareness of the new postoperative regimen by treating therapists, patients treated from January 2012 to April 2015 were included in the late active motion protocol and patients treated between October 2015 and April 2017 were included in the early active motion protocol.

Late active motion protocol

Patients in the late active motion group received a cast immobilization for 10-16 days, followed by a wrist orthosis for 24 h/d. Patients were allowed to start with ROM of the fingers and the thumb. In weeks 5-6, patients could start with ROM of the wrist, coordination exercises (holding a 0.5-kg dumbbell in stable position) and reducing the use of the wrist orthosis. Week 7-13 consisted of improving coordination and increasing strength and stability.

Early active motion protocol

Patients in the early active motion group received a cast immobilization for 3-5 days, followed by use of a wrist orthosis for 24 h/d. During week 2, patients were allowed to start ROM of the wrist. The treatment protocol suggested care with flexion in this phase.[14] After 5 weeks, ROM of the wrist was increased to wrist flexion to 30° and the use of the wrist orthosis was reduced. In weeks 7-13 coordination, strength and stability training were optimized.



10-16 days	Cast immobilization.	3-5 days	Cast immobilization.
	24h/day wrist splint. Optimizing ROM of the fingers and thumb.		24h/day wrist splint. Optimizing ROM of the fingers and thumb. ROM of the wrist (care with flexion in this phase).
	ROM of the wrist, coordination exercises, reducing the use of the wrist splint.		Increasing to wrist flexion to 30°, reducing the use of the wrist splint.
	Coordination, strength and stability training.		Coordination, strength and stability training.

Variables and data sources

The primary study outcome was PRWHE Dutch Language Version (DLV) scores.[15,16] This tool is a valid indicator of wrist pain and disability. The PRWHE is a 15-item questionnaire, allowing the patients to rate their level of pain and disability on a 1 to 10 scale. Two subscales were derived from the questionnaire indicating pain and function. A total score of 0 indicates no pain or functional impairment, a total score of 100 indicates worst possible pain and function.

For pain the Visual Analogue Scale (VAS), reflecting the sensation of pain on a 0 to 100-point scale; 0 is no pain, 100 is excruciating pain.

ROM was measured with a goniometer of the affected wrist in extension, flexion, ulnar deviation, radial deviation, pronation and supination according to the recommendations of the American Society of Hand Therapists.[17] Grip strength was measured with a dynamometer following Mathiowetz et al.[18] Complications were classified according to a modified version of the original Clavien et al classification for post-operative complications (Appendix E1).[19,20] After 3 months, satisfaction with the treatment result was collected with a validated questionnaire following de Ridder et al.[21] The return to work was reported by questionnaires whose validity and reliability are unknown. Patients with incomplete baseline and 3-month follow-up scores from the PRWHE-DLV, VAS at rest and VAS during physical load were excluded from analysis.

Study size

We used a small to medium effect size of 0.35 as the noninferiority margin resulting in a minimal sample size of 70 participants for a power of 0.80 ($\alpha = 0.05$).

Statistical analysis

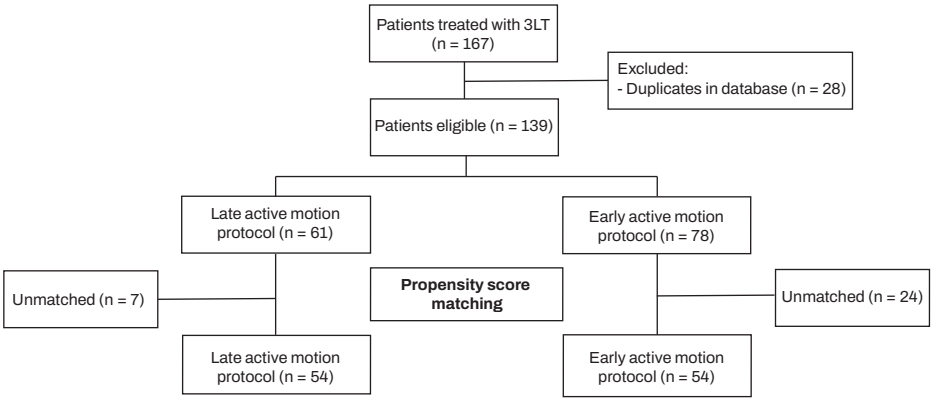
Because comparing groups in an observational design has its limitations, we used propensity score matching according to a nearest neighbor algorithm to limit the impact of covariates in this observational study. A propensity score is the probability a patient will be assigned to a particular treatment, given the observed covariates. [22,23] Propensity score matching allows for the comparison of matched individuals, because the only remaining difference in covariates is whether they were treated with the intervention of interest or not. Propensity scores were estimated based on the following baseline characteristics: age, sex, body mass index (BMI), smoking, diabetes, type of work, dominant side treated, duration of symptoms in months, PRWHE-DLV score (at baseline), and scores on the VAS at rest and VAS during physical load (at baseline). A caliper of width equal to 0.2 of the standard deviation of the logit of the propensity score was considered to match the tolerance. [24] This caliper is used to limit the range within which an individual was considered to be matched with another individual. To assess whether the matching

of individuals worked, we calculated the standardized mean difference between the matched and unmatched patients, and a value greater than 0.10 was regarded as indicating a substantial imbalance between groups. To demonstrate noninferiority, superiority, or equivalence, the effect sizes of the PRWHE-DLV, VAS at rest, VAS during physical load, ROM, and grip strength data at 3 months were calculated. Values were considered to be equal if the 95% confidence intervals were within both negative and positive equivalence margins. Noninferiority was demonstrated if 1 side of the 95% confidence interval was outside the noninferiority margin.[25] A small-to-medium effect size of 0.35 was held as the non-inferiority margin.[26] To compare categorical and nonparametric data a paired Wilcoxon rank-sum test was used. To compare complications and return to work a chi-squared test was used. *P* values <.05 were considered to be significant.

Results

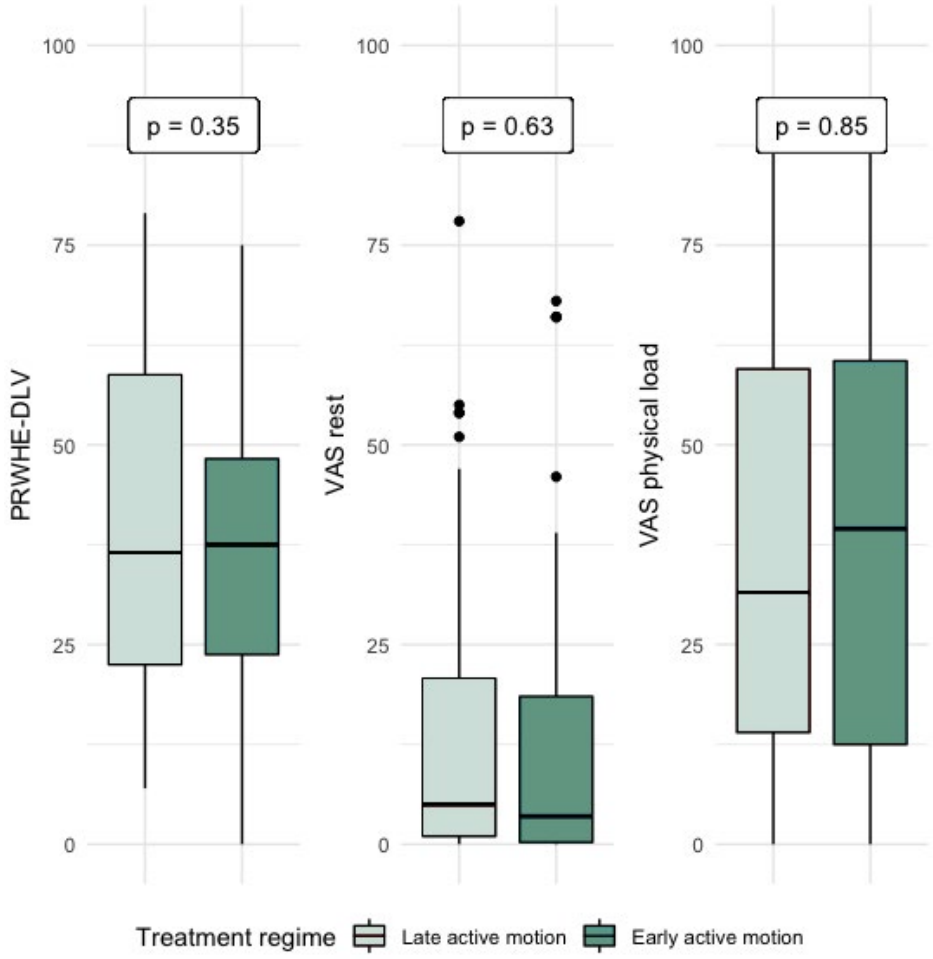
In total, 167 patients underwent surgery between January 2012 and April 2015 and between October 2015 and April 2017. Removing duplicates in the database resulted in 139 patients from 10 different clinics. None of these patients had to be excluded due to incomplete baseline characteristics or incomplete 3-month follow-up scores on the PRWHE-DLV, VAS at rest, or VAS during physical load. After matching, 54 patients were included in the late active motion group and 54 patients were included in the early active motion group (Fig. 2). All standardized mean differences were <0.10, except for those for type of work (0.152), BMI (0.126), and dominant side treated (0.112; Table 1).

Figure 2. Study flow chart, demonstrating 54 participants per group were included in this study after propensity score matching.



The PRWHE-DLV scores in the late active motion group (median, 36.5; interquartile range [IQR], 22.5-58.8) did not differ significantly compared to those in the early active motion group (median, 37.5; IQR, 23.8-48.2; P=.35; Fig. 3). Scores for pain using the VAS at rest (late active motion protocol: median, 5.0 [IQR, 1.00-20.75]; early active motion protocol: median, 3.5 [IQR, 0.25-18.50]) and VAS during physical load (late active motion: median, 31.5 [IQR, 14.00-59.50]; early active motion protocol: median, 39.5 [IQR, 12.50-60.50]) did not differ significantly between groups (*P*=.63 and *P*=.85, respectively). Measured effect sizes were 0.197 (95% confidence interval [CI], 0.19 to 0.58) for the PRWHE-DLV, 0.056 (95% CI, 0.33 to 0.44) for the VAS in rest, and -0.036 (95% CI, 0.42 to 0.35) for the VAS during physical load, and were within the predefined margin of 0.35, which indicates noninferiority.

Figure 3, Boxplots representing PRWHE, VAS at rest and VAS during physical load of both treatment regimens after 3 months.



No significant increase in the number of observed complications was found (*P*=.54; Table 2). 2 patients in the early active motion group were operated on for triangular fibrocartilage complex lesions. We did not consider this to be a complication of the 3LT procedure; therefore, these patients were not reported in Table 2. Furthermore, no significant differences were found in return to work (n = 45; *P*=.51), ROM (n = 76), grip strength (n = 85; *P*=.65), or satisfaction with the treatment result (*P*=.36). Range of motion and grip strength were within the noninferiority margin of 0.35, indicating noninferiority (Table 3).

Table 1 Baseline Characteristics Before and After Propensity Score Matching.*

	All Patients			Matched Patients		
Variables	Late Active Motion Protocol (n = 61)	Early Active Motion Protocol (n = 78)	Standardized Mean Difference	Late Active Motion Protocol (n = 54)	Early Active Motion Protocol (n = 54)	Standardized Mean Difference
Age, y	47 (38-55)	51 (40-58)	0.144	47 (39-56)	50 (38-57)	0.075
Sex, women %	28 (45)	34 (43)	0.047	26 (48)	24 (44)	0.074
BMI	26 (23-28)	25 (23-29)	0.009	26 (23-28)	25 (23-28)	0.126
Smoking, no, %	50 (81)	65 (83)	0.036	44 (82)	42 (78)	0.092
Diabetes, yes, %	1 (0.02)	0 (0)	0.183	0 (0)	0 (0)	<0.001
Type of work, %			0.220			0.152
Not working	14 (23)	22 (28)		14 (26)	16 (30)	
Light work	21 (34)	23 (29)		17 (32)	14 (26)	
Work	16 (26)	16 (21)		13 (25)	15 (28)	
Heavy work	10 (16)	17 (22)		10 (19)	9 (17)	
Dominant side treated, %	35 (57)	42 (54)	0.071	31 (57)	28 (52)	0.112
Duration of symptoms, months	20 (5-24)	18 (6-14)	0.084	10 (5-24)	11 (6-24)	0.042
PRWHE total	62 (45-70)	56 (40-68)	0.148	62 (44-70)	57 (42-68)	0.053
VAS at rest	34 (13-51)	33 (12-57)	0.069	38 (14-53)	28 (12-57)	0.014
VAS during physical load	72 (59-78)	69 (47-79)	0.162	71 (56-77)	69 (49-80)	0.059

*Continuous variables are shown as median (IQR). Discrete variables as n (%).

Table 2 Complications Following the Late and Early Active Motion Protocols.

Complications*	Late Active Motion Protocol (n=54)	Early Active Motion Protocol (n=54)	*P*- value
Overall number of complications	Overall: 20	Overall: 17	0.54
Grade I	total: 12	total: 12	
Persistent pain, treated with extra analgesics, additional hand therapy, ortosis fabrication, or cast	10	8	
Temporary sensory disturbance	2	2	
Scar tenderness	0	2	
Grade II	total: 7	total: 3	
Infection, treated with antibiotics	3	0	
Persistend pain, treated with injection of steroids or analgetics	4	3	
Grade III			
Grade IIIa	total: 0	total: 1	
Release of the first extensor compartment	0	1	
Grade IIIb	total: 1	total: 1	
Flexor carpi radialis synovectomy	0	1	
Proximal row carpectomy	1	0	
Grade IIIc	total: 0	total: 0	
Complex Regional Pain Syndrome	0	0	

Complications were classified according to modified criteria from Clavien et al.[19]

Table 3 Return to Work, ROM, Grip Strength and Satisfaction with Care*

Currently working, %	Late Active Motion Protocol (n = 23)	Early Active Motion Protocol (n = 22)	*P*-value	Effect size	95% CI
Yes	21 (91)	18 (82)	.51		
No, because of wrist issues	0	0			
No, because of other reasons	2 (9)	4 (18)			
Original work	16 (76)	10 (56)			
Range of motion, degrees (IQR)	(n = 41)	(n = 35)			
Extension	48 (42-56)	48 (40-60)	.78	-0.113	-0.54 - 0.32
Flexion	38 (30-48)	39 (30-44)	.95	-0.039	-0.47 - 0.39
Radial deviation	15 (11-18)	14 (11-19)	.87	0.073	-0.37 - 0.52
Ulnar deviation	20 (17-30)	22 (19-30)	.40	-0.189	-0.64 - 0.26
Supination	78 (70-82)	77 (70-85)	.73	-0.115	-0.57 - 0.34
Pronation	80 (75-85)	78 (70-82)	.32	0.091	0.37 - 0.55
Grip strength, kilograms (IQR)	(n = 44)	(n = 41)			
	24 (18-37)	26 (20-32)	.65	-0.011	-0.44 - 0.42
Satisfaction with care, %	(n = 54)	(n = 54)			
Not at all	3 (6)	1 (2)	.36		
Poorly	7 (13)	5 (9)			
Moderate	14 (26)	18 (33)			
Good	26 (48)	24 (44)			
Excellent	4 (7)	6 (11)			

*Continuous variables are shown as medians (IQRs). Discrete variables as are shown as n (%).

Discussion

Different post-operative immobilization regimens following 3-LT reconstruction ranging from 2 weeks to 8 weeks have been reported.[5,9–12] If a shorter immobilization and earlier start with ROM after 3LT lead to similar results and does not increase the number of complications, patients may be able to recover sooner. Our study results suggest postoperative PRHWE-DLV and pain scores following an early active motion protocol are non-inferior compared to those of a late active motion protocol. Furthermore, early active motion does not lead to an increase in complications, differences in ROM and grip strength, or less satisfaction with the treatment result. An earlier return to work with early active motion was not observed.

This study has several limitations. First, the study had a limited sample size of 108 patients. While previous studies of wrist surgery for scapholunate interosseous ligament injuries reported 20-117 patients and this study has a relatively larger sample size than other studies, the sample size remains small in absolute terms. Therefore, it could have led to an underestimation of uncommon complications, such as failure of the reconstruction. Second, the standardized mean differences of type of work, dominant side treated, and BMI were slightly above the 0.10 limit. This resulted in a slight imbalance between groups, which we believe is too small to affect the study results. Third, due to the observational design of this study, patients could have been treated according to a different postoperative regimen during the implementation of the new protocol. However, all therapists were trained when the protocol change took place, and we included a half-year inclusion gap to reduce this probability. Also, we randomly checked several included patients and found the protocols were adequately followed. Therefore, we are confident that protocol compliance was sufficient and that our results are valid. Still, future randomized studies are needed to validate our findings. Fourth, we only studied data 3 months after surgery. We think most of the impact of different rehabilitation protocols can be measured during the first 12 weeks after surgery. Fifth, while all patients remained in regular follow-up, some failed to report their return to work, ROM, and grip strength, and this resulted in less and incomplete data. Therefore, some of these subgroup analyses, especially that for return to work, may have been underpowered.

Despite these limitations, our study results are in line with those of several other studies. Previous studies with a mean follow-up of 2 years found mean Disabilities of the Arm, Shoulder, and Hand scores ranging from 20 to 31 and a mean postoperative Patient-Rated Wrist Evaluation score of 33.6.[9,11] The main difference with our data is that the previously reported groups were small (n = 20) and the patient-reported outcome measures were recorded later after surgery. Median VAS pain scores did not differ between the late and early active motion groups in our

study, and are similar to the mean VAS pain score of 30 reported by Elgammal and Lukas[9], and the subdivided pain scores of 16 on the VAS at rest and 49 on the VAS during physical load reported by Pauchard et al.[11]

A review comparing capsulodesis techniques with tenodesis techniques reported that 3% of all tenodesis procedures experienced infection and 6% required secondary surgery.[27] This review included multiple tenodesis techniques like the Brunelli tenodesis technique with the flexor carpi radialis tendon anchoring at the distal radius and at the lunate, the Van den Abbeele et al[7] technique and the Garcia-Elias et al[5] (3LT) modifications. Although our study only investigated the 3LT, the complication rates are comparable to those reported in the review. Three of 108 (3%) patients had an infection and 4 of 108 (4%) required secondary surgery. We did not observe an increase in complications, especially failure of the reconstruction, when the early active motion protocol was followed.

With a minimum of 12 months of follow up, Athlani et al[12] reported that 90% of their patients were able to return to their original job. In our study, 91% of the patients in the late active motion group and 82% in the early active motion group returned to work, of which 76% and 56%, respectively, returned to their original work. All patients that were not able to return to work reported that their reasons were not related to their wrist. The lower rates of return to original work observed in this study might be due to the shorter follow-up duration of 3 months used in this study. We did not observe any differences in rates of return to work; a possible explanation for this could be that our subgroup analysis might have been underpowered to determine between-group differences. More insight in returns to activities and work is needed for clinician decision-making. The impairments of ROM and grip strength are similar to those of previous studies, and both treatment protocol groups showed comparable results.[5,9,11]

Most patients in both groups were satisfied with the treatment result (scoring it as good or excellent), which is in line with earlier reports of high satisfaction rates.[28]

In conclusion, this study suggests that an early active motion regimen is noninferior to a late active motion in terms of patient-reported outcomes, pain, ROM, and grip strength. Furthermore, early active motion does not lead to more complications after 3LT. However, it does not result in a higher rate of return to work after 3 months. Therefore, we conclude that early active motion is safe and could be recommended due to its potential benefits compared to late active motion. More studies on early active motion that address patient comfort and earlier return to activities and work are needed.

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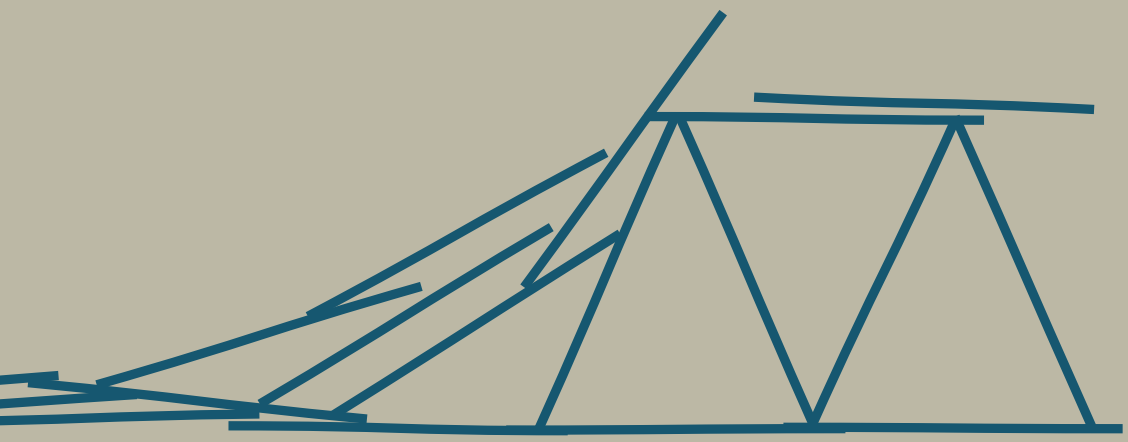
9 Concomitant ligament injuries can be left untreated during surgery of distal radial fractures.



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Abstract

Instability of the distal radioulnar joint and scapholunate dissociation may cause pain, functional impairment and subsequent arthrosis. There is no consensus about whether these injuries should be treated acutely in patients undergoing surgery for distal radial fractures. We conducted a prospective cohort study to determine whether concomitant distal radioulnar joint instability or scapholunate dissociation negatively influences patient related outcome in these patients. The primary outcome was the Patient Reported Wrist/Hand Evaluation at 6 and 12 months after surgery. Out of 62 patients, 58% and 27% had intraoperative distal radioulnar joint instability and scapholunate dissociation respectively. No significant differences were found in patient-reported scores at follow-up between patients with stable and unstable distal radioulnar joints, nor between patients with and without scapholunate dissociation. Sixty-three percent of patients with an unstable distal radioulnar joint during surgery were stable on retesting after 6 months. Our study suggests that a wait and see policy in these patients therefore seems reasonable.

Level of evidence: III

Introduction

The predominant view is that distal radioulnar joint (DRUJ) instability and scapholunate dissociation (SLD) require treatment (usually surgical) to prevent pain, functional impairment and subsequent arthrosis.[1–5] However, there is debate about whether these injuries should be treated at the time a patient is operatively treated for a distal radials fracture (DRF). Wijffels et al. (2017)[6] found no correlation between DRUJ instability and long-term functional outcome in patients with conservatively treated DRFs.

Arthroscopic studies report an incidence of concomitant scapholunate (SL) ligament and triangular fibrocartilage complex (TFCC) injuries in patients with DRFs of 78% and 54% respectively.[7–9] However, treating these concomitant ligamentous injuries may lead to wrist stiffness.[10] Moreover, several studies describe a benign natural history of these injuries and of them not requiring further treatment. Two groups prospectively studied the outcome of untreated partial (Grade 1 or 2) and complete (Grade 3) SL or TFCC tears in patients who were surgically treated for a displaced DRF with a follow-up of 13 to 15 years.[7,8,11] The results suggest that both SL and TFCC lesions did not influence long-term subjective, objective or radiographic outcomes.

In most cases, arthroscopy will not be available and DRUJ stability will be tested intra-operatively. In most cases the ballottement test is used to assess the stability of the DRUJ. SLD can be assessed with wrist cineradiography with a described sensitivity of 90% and a specificity of 97%.[12]

The primary aim of this study was to determine whether concomitant DRUJ instability or SLD negatively influence patient-related outcomes in adult patients treated operatively for a DRF with a minimum follow up of 1 year. Secondary outcomes were range of motion (ROM), grip strength and DRUJ stability.

Methods

We conducted a multicenter prospective cohort study following the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement.

This study was approved by the Institutional Review Board and all patients underwent open reduction and internal fixation using locking plates. Each surgical procedure took place in two different hospitals of which one was a teaching hospital.

We included all consecutive patients of 18 years and older who underwent an operative reduction and internal fixation (ORIF) for a distal radial fracture between May 2020 and April 2021. All surgical procedures were carried out by two surgeons (NS, BC) who routinely test DRUJ stability and use wrist cineradiography during surgery. Exclusion criteria were: patients over 75 years; impaired wrist function before the distal radial fracture; neurological disorders; incomplete baseline data; or incomplete data at 6 months follow-up. Other exclusion criteria included patients with connective tissue disease, joint hypermobility or an ipsilateral distal radial fracture within 3 months before the treated injury. Fracture characteristics including carpal alignment, radial height, dorsal tilt, radial inclination and SL-gap were measured on the initial plain trauma radiographs.

Instability of the DRUJ was tested directly after fracture fixation with the ballottement test, also known as the DRUJ stress test.[13] This test was done by stabilizing the distal radius with one hand and grasping the ulnar head with the other in the neutral position. The test was considered to be positive if there was significantly more laxity on the fractured side compared with the contralateral side. The instability was categorized as: Grade 0, stable; Grade 1, unstable but with an end feeling; and Grade 2, grossly unstable with an ulnar head that could be dislocated out of the sigmoid notch.

Additionally, wrist cineradiography was used to identify SL ligament injuries. During wrist cineradiography, passive radial and ulnar deviation and flexion-extension of the wrist were examined under fluoroscopy. Cineradiography was considered to be positive for a SLD if the scaphoid and lunate did not move synchronously in either of the views or if a gap appeared between the bones during motion. In the lateral view, cineradiography was considered to be positive if the lunate did not cross the 0° line of the radiolunate angle from extension to flexion.[12,14] Static and dynamic SLD were both considered as SL unstable. Neither DRUJ instability nor SLD affected the duration of postoperative immobilization.

The primary outcome was the Patient Reported Wrist/Hand Evaluation Dutch Language Version (PRWHE-DLV), which is the Dutch version of the original

PRWHE.[15] The PRWHE is a scale for hand and forearm functionality, consisting of 15 items, designed to measure pain and disability during activities. Each item can be scored from 0 to 10, with 0 indicating no pain or functional impairment and 10 indicating the worst pain and total dysfunction. A total score of 0 indicates no pain and impairment, and a total score of 100 indicates the worst possible pain and function. The PRWHE was obtained at 6 and 12 months after surgery.

Range of motion (ROM) of the affected wrist was measured with a goniometer in extension, flexion, ulnar deviation, radial deviation, pronation and supination.[16] Grip strength in the hand on the affected side was measured with a dynamometer.[17]

Carpal alignment was measured with the perpendicular method on the preoperative radiographs, as described by Selles et al.[18] This method describes a line along the inner rim of the anterior cortex of the radius, and one perpendicular line to the center of the capitate. The carpus was considered to be aligned if the length between the perpendicular and the capitate head was within 5 mm.

As the use of regional or general anaesthesia might influence stability of the wrist, the type of anaesthesia used was noted.

Patients were monitored at the outpatient clinic at 6 weeks, 6 months and 12 months after surgery. At 6 months, the PRWHE, range of motion and grip strength were assessed. The DRUJ stress test was repeated at 6 months. At 12 months the PRWHE was re-assessed. All measurements were made by trained research personnel (DB, BD). Complications were recorded and specified.

Statistical analysis

Normality of continuous data was tested with the Shapiro-Wilk test and homogeneity of variances was tested using the Levene's test. For continuous data, the mean and standard deviation (parametric data) or the median and 25^{th} to 75^{th} percentiles (non-parametric data) were reported. For categorical data numbers and frequencies were reported. To compare categorical and non-parametric data, a Wilcoxon rank sum test was used. To compare dichotomous variables with other dichotomous variables, the chi-squared and Fisher's exact tests were used. A p-value of <0.05 was taken as the threshold of statistical significance in all tests and all tests were two-sided. Missing values were not replaced by generated data (e.g. means or linear regression models) or new patients. Data was analysed using R, version 1.3.1.

Results

Baseline

Sixty-six patients met the inclusion criteria. Four patients were excluded from analysis because of incomplete baseline data or loss to follow up at 6 months, leading to the analysis of 62 patients. Four further patients were lost to follow-up at 12 months. The baseline characteristics are given in Table 1.

There was a significant difference between the radial height on the initial trauma radiographs of patients with intraoperative DRUJ instability and an intraoperatively stable DRUJ (Table 1). The length of the perpendicular to the center of the capitate on the initial trauma radiographs differed significantly between patients with SLD and patients without SLD. Eleven of the 36 patients with intraoperative DRUJ instability also had SLD, compared with 6 of the 26 patients with an intraoperatively stable DRUJ ($p = 0.52$).

PRWHE

The differences between the PRWHE reported by patients with a stable DRUJ (24, IQR 4 to 54) and patients with an unstable DRUJ during surgery (26, IQR 10 to 59) were not significant at 6 months ($p = 0.34$). Nor were there any significant differences in the 57 patients at 12 months follow-up (stable 9, IQR 0 to 25; unstable 14, IQR 5 to 37; $p = 0.20$). The PRHWE reported by patients with SLD (23, IQR 10 to 65) did not significantly differ from the PRHWE reported by the patients without SLD (25, IQR 9 to 54) at 6 months ($p = 0.72$) or at 12 months follow-up (no SLD 16, IQR 4 to 35; with SLD 5, IQR 0 to 39; $p = 0.52$). When comparing the PRWHE in patients with both unstable DRUJ and SLD with patients without concomitant injuries or only one type of injury we found that in patients with DRUJ Grades 1 and 2 and SLD the PRWHE was 6.0 (IQR 1.4 to 32.1). When there was no SLD and no DRUJ or only one injury, the PRWHE was 14.5 (IQR 3.0 to 32.3) after 1 year, which was not significantly different ($p = 0.72$). This was also the case for the PRWHE in patients with DRUJ and SLD (6.0, IQR 1.4 to 32.1) versus only those with no SLD and DRUJ instability (15, IQR 0.8 to 25; $p = 0.88$).

Range of motion and grip strength

No significant differences in range of motion or grip strength were found (Table 2).

Intra-operative DRUJ instability and follow-up

Fifty-eight percent (36/62) of all patients were graded with a DRUJ instability of grade 1 or 2 during surgery. Because a ballottement test was not performed at 6 months follow-up in four of the patients, they were excluded from this analysis. Of the remaining 32 patients, 63 % (20/32) had a stable DRUJ after 6 months. Of the 26 operatively graded stable DRUJs, 12 were graded as unstable after 6 months.

Table 1. Baseline characteristics.

		DRUJ stability				SL Dissociation		
Variables	**Overall,** N = 62	**DRUJ 0,** N = 26	**DRUJ Grade 1 or 2,** N = 36	***p*-value**	**No SLD,** N = 45	**SLD,** N = 17 (Static/ Dynamic)	***p*-value**
Age	62.5 (52.2 to 69.8)	67.0 (55.0 to 71.8)	61.0 (39.8 to 67.0)	0.068	63.0 (53.0 to 72.0)	60.0 (52.0 to 67.0)	0.364
Sex, female (%)	49 (79%)	18 (69%)	31 (86%)	0.107	35 (78%)	14 (82%)	0.999
Dominant side treated, yes (%)	27 (44%)	11 (42%)	16 (44%)	0.867	20 (44%)	7 (41%)	0.817
AO classification				0.642			0.206
a	7 (11%)	3 (12%)	4 (11%)		7 (16%)	0 (0%)	
b	5 (8.1%)	1 (3.8%)	4 (11%)		4 (8.9%)	1 (5.9%)	
c	50 (81%)	22 (85%)	28 (78%)		34 (76%)	16 (94%)	
carpal alignment, mm	10.0 (6.0 to 14.8)	8.5 (5.2 to 14.8)	11.0 (6.8 to 13.5)	0.534	9.0 (5.0 to 13.0)	13.0 (11.0 to 18.0)	**0.038**
radial height, mm	8.0 (5.2 to 10.0)	9.0 (6.5 to 10.0)	7.0 (4.0 to 9.2)	**0.032**	8.0 (5.0 to 10.0)	8.0 (6.0 to 9.0)	0.579
dorsal tilt, degrees	19 (7 to 29)	20 (11 to 27)	17 (-4 to 31)	0.663	15 (5 to 27)	27 (15 to 31)	0.088
radial inclination, degrees	15 (10 to 20)	17 (14 to 20)	14 (10 to 19)	0.084	16 (11 to 19)	15 (8 to 20)	0.492
SL gap, mm	1.6 (1.3 to 1.9)	1.7 (1.4 to 1.9)	1.5 (1.2 to 1.9)	0.215	1.6 (1.3 to 1.8)	1.8 (1.3 to 2.0)	0.447
DRUJ stability, grades 1 or 2	36 (58%)				25 (56%)	11 (65%)	0.515
SLD (Static/Dynamic), Yes	17 (27%)	6 (23%)	11 (31%)	0.515			

Continuous data is presented as medians with interquartile ranges. Dichotomous and categorical data are reported as frequencies with percentages.

DRUJ: distal radioulnar Joint; SL: scapholunate; SLD: scapholunate dissociation.

Statistically significant p-values shown in bold font.

Table 2. Range of motion and grip strength after operatively treated distal radius fracture after 6 months follow-up.

		DRUJ stability			SL dissociation		
Variables	**Overall,** N = 62	**DRUJ Grade 0,** N = 26	**DRUJ Grade 1 or 2,** N = 36	**p-value**	**No SLD,** N = 45	**SLD, N = 17 (Static/ Dynamic)**	**p-value**
Flexion, degrees	65 (55 to 75)	67 (56 to 79)	65 (50 to 75)	0.55	65 (55 to 75)	65 (50 to 70)	0.30
Extension, degrees	70 (60 to 80)	75 (60 to 80)	68 (55 to 80)	0.41	75 (60 to 80)	60 (55 to 75)	0.14
pronation, degrees	80 (80 to 80)	80 (80 to 80)	80 (80 to 80)	0.89	80 (80 to 80)	80 (80 to 80)	0.55
supination, degrees	85 (75 to 85)	85 (75 to 85)	85 (75 to 85)	1.00	85 (75 to 85)	80 (75 to 85)	0.38
Grip strength, kg	18 (14 to 27)	21 (14 to 27)	18 (14 to 25)	0.57	20 (15 to 28)	15 (12 to 24)	0.18

Continuous data is presented as medians with interquartile ranges.
DRUJ: distal radioulnar joint; SL: scapholunate; SLD: scapholunate dissociation

Complications

In 22 of the initial 66 patients, the anterior locking plate was removed. The reasons for removal were plate irritation in 16 cases, carpal tunnel syndrome in two cases, de Quervain's disease in two cases, DRUJ osteoarthritis in one case and dorsal dislocation of the ulna out of the sigmoid notch in a patient with a dorsal ulna corner fragment. However, this last patient had a PRWHE score of 0 after 12 months follow-up. None of the patients were treated for persistent DRUJ instability or SLD.

Discussion

The acute treatment of DRUJ instability or SLD, or both, concomitant with ORIF of a distal radial fracture is a subject of debate and uncertainty.[19] This study found similar patient-reported outcomes at 6 and 12 months follow-up in patients with and without DRUJ instability or SLD, or both that were surgically treated for a distal radial fracture but without treating the ligamentous injury. No differences in range of motion and grip strength were found.

This study found an SLD incidence of 27% which is higher than the previously reported 3.6% to 13%.[20,21] A study using arthroscopy during surgery for DRF reported a prevalence of all grades of SL-injuries up to 50%.[9] We assume the differences in reported incidence are due the use of plain radiographs versus dynamic testing with cineradiography or arthroscopy.

Previous studies on SL injuries show comparable results. Swart and Tang 2017[22] found no differences in arthroscopically evaluated DRFs with concomitant SL injuries in patient-reported outcomes after 1 year follow-up. Other studies reported no differences in patient-reported outcome after surgically treated DRFs with concomitant SL injuries which is in line with our results.[8,21]

The results of this study for the DRUJ are in accordance with previous studies. Mrkonjic et al. 2012[7] performed a prospective study of 51 patients to analyse the outcome of untreated partial and complete TFCC ruptures in patients who were surgically treated for a displaced DRF with a follow-up of 13-15 years. Apart from a better grip strength in wrists with a stable DRUJ, this study found no differences in patient reported outcome.[7]

In contrast, Lindau et al. 2002[11] reported no difference in grip strength between patients with and without DRUJ instability 6 years after DRF treatment. Also, in contrast with our results, they found a difference in patient-reported outcomes in favour of patients without DRUJ instability.

Lee et al. 2016[23] randomized 157 patients with DRFs with intraoperative DRUJ instability to non-surgical treatment and surgical repair and found no differences in range of motion and patient-reported outcome after 12 months. Similarly, no differences were found in patients treated non-surgically for a DRF between patients with and without DRUJ instability.[6]

We found that 20/32 (63%) of the patients that were considered to have an intraoperatively unstable DRUJ, had a stable DRUJ at 6 months follow-up. Twelve of the 26 (46%) patients that were considered to have a stable DRUJ at operation, showed instability at 6 months follow-up. Spontaneous healing of the TFCC and

ligaments may explain why DRUJs become stable over time. Increasing laxity or the decline of secondary stabilizers may explain progressive DRUJ instability over time after DRFs. However, poor sensitivity and specificity or interobserver agreement of the ballottement test should not be ruled out in the interpretation of these results. Previous studies on upper extremity conditions such as SLD or proximal humeral fractures have already noted limited reliability and reproducibility of diagnostic tests.[24,25] A recent study on the reliability of the ballottement test reported a low sensitivity of 24% and concluded the test could be unreliable.[26] In our study, the ballottement test was carried out during surgery. As muscle tone is influenced by general and regional anaesthesia, the reproducibility of the test might even be worse.

This study has several other limitations. As only one patient had static SLD, our study mostly relates to dynamic SLD. Moreover, the DRUJ stress test at follow-up was done by different physicians, which may have led to interobserver variability in grading. However, all the researchers were trained in performing the ballottement test and this way of obtaining the data may correspond to the day-to-day situation.

In conclusion, our study suggests that intraoperative DRUJ instability or SLD does not affect the outcome in patients operatively treated for a distal radial fracture after 1 year. Similar results were found for range of motion and grip strength. A "wait and see" policy in these patients therefore seems reasonable. More than half of the patients with an unstable DRUJ during surgery were stable on testing after 6 months. However, the reproducibility of DRUJ testing and therefore its clinical importance is unsure.

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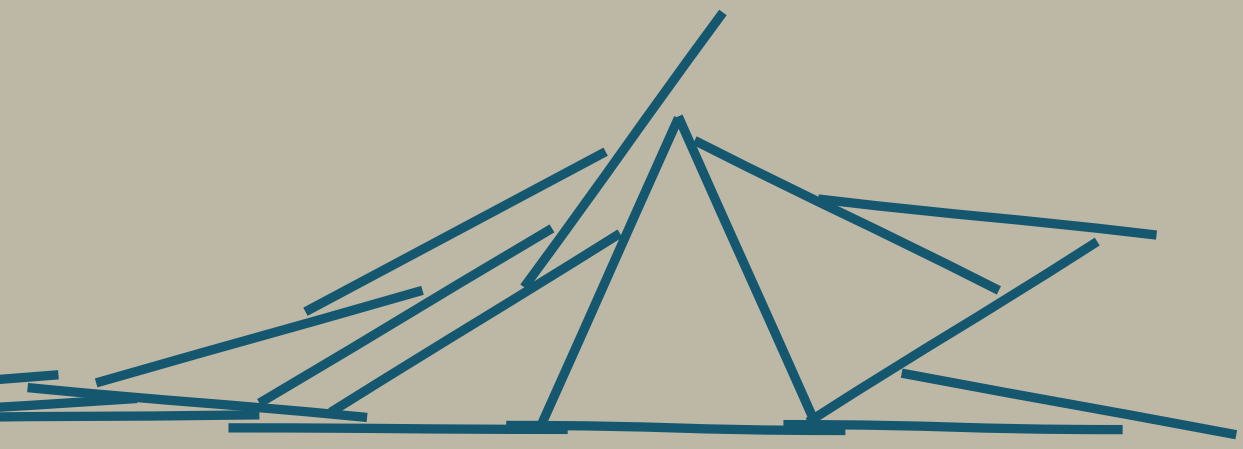
Part IV

General discussion, future perspectives, and summary

10 General discussion and future perspectives



General discussion and future perspectives

While scapholunate ligament (SL) injury is the most frequently diagnosed wrist ligament injury, correct diagnosis and interpretation, a proper understanding of the natural course of the injury and adequate treatment remain difficult, and therefore SL injury constitutes a bewildering problem.[1,2] In an attempt to obtain more knowledge about this pathology, this thesis addressed multiple aspects related to the biomechanical properties following surgery, the diagnostics, the treatment recommendations and the outcomes of treatment for SL ligament injuries and subsequent scapholunate dysfunction. In this final chapter, we discuss this thesis's findings, its constraints, its implications, and future perspectives.

The discussion is subdivided into three parts, not necessarily following the order of the previous chapters. The first part focusses on early active motion after the most common surgical procedures for scapholunate dysfunction. The second part sheds light on the 'scaphoid-lunate advanced collapse (SLAC) paradigm'. The final part addresses uncertainties which are inextricably linked to scapholunate dysfunction at the level of the pathology, the patient, and the physician.

Early active motion after surgical treatment of scapholunate dysfunction

The duration of joint immobilization and the start of subsequent rehabilitation should be based on evidence and informed decision making. This part of the discussion addresses the described rehabilitation regimens after reconstructive procedures for scapholunate ligament injuries, exploring the biomechanical aspects of the wrist after the dorsal capsulodesis according to Mayo and the 3-Ligament tenodesis.[3,4] The patients that are discussed were treated following an early active or late active motion protocol.

In **Chapter 7** of this thesis, a systematic review demonstrated that SL injuries are treated with many different surgical procedures followed by diverse periods of immobilization. Even when procedures were subdivided into capsulodesis and tenodesis, the executed techniques varied widely. For tenodesis techniques, the immobilization ranged from 1 to 8 weeks, and for capsulodesis from 4 to 8 weeks. These diversities in surgical procedures and post-operative rehabilitation protocols pose a challenge for any attempt to analyze and improve treatment protocols and is indicative for the current level of evidence.

It is necessary to explore why some surgeons immobilize the wrist for 8 weeks and others for just 1 week. Future studies should identify the factors that were involved in those treatment decisions in terms of pathology, patient characteristics, surgeon preferences, and treatment options. The explanatory parameters should then be tested in a prospective way to lay the foundations for an evidence-based duration for joint immobilization and for the start of rehabilitation.

As there are no validated parameters yet, the review in **Chapter 7** visualized and summarized the differences between currently performed treatment protocols. For both the capsulodesis and the tenodesis techniques, no differences were found between short-term (≤6 weeks) and longer (>6 weeks) immobilization in terms of patient-reported outcome measures (PROMs), pain, range of motion (ROM), grip strength or number of complications. The labels short-term and long-term are arbitrary as some studies applied casting for one or two weeks, while others immobilized the wrist for eight weeks.[5,6] Although most studies had small sample sizes, did not use blinding or randomization and lacked long-term follow-up, the results suggested that relatively shorter immobilization and subsequent earlier rehabilitation might lead to similar results as longer immobilization.

While these results are indicative, it would be valuable to have a better understanding of the feasibility and the constraints of movement after scapholunate joint reconstruction at the biomechanical level. Since dynamic imaging of ligaments is difficult, valuable information can be provided by experiments based on anatomic

specimens. Therefore, like Vesalius in 1543, the procedures were performed on human specimens and repeatedly tested.[7] **Chapter 2** and **Chapter 3** compared the outcomes of two common surgical procedures used for the treatment of scapholunate dysfunction: Mayo Capsulodesis and the 3-Ligament Tenodesis (3-LT).[8]

Chapter 2 revealed that after a capsulodesis procedure, elongation mainly occurs at the dorsal intercarpal complex during flexion.[8] Additionally, elongation of the dorsal intercarpal reconstruction was minimal. No observations were reported of failure of the dorsal intercarpal reconstruction or the bone anchor. However, sutures that connected the dorsal intercarpal complex loosened between 55 and 60 degrees of flexion. In **Chapter 3,** the biomechanics after 3-LT suggested that the flexor carpi radialis tendon slip shows relatively little elongation, and that elongation mainly occurs at the dorsal intercarpal complex. No failures of the radiotriquetral ligament were observed, nor any pull-outs of the bone anchor or any flexor carpi radialis tendon slip failures. However, we did observe suture loosening at the proximal side of the dorsal intercarpal complex after 30 degrees flexion.

Limitations of the experiments executed in **Chapter 2** and **Chapter 3** were the limited number of embalmed anatomic specimen, which can show shrinkage, the age of the specimen and the lack of scar tissue. Secondly, our experiments tested flexion; additional insights may be gained by exploring the biomechanics during extension, radial and ulnar deviation, which also leads to scaphoid movement.[9] Thirdly, we tested isolated SL injuries, and consequently, no conclusions can be drawn regarding SL injuries in combination with injuries of secondary stabilizers.

Despite these limitations, both experiments justified the hypothesis that the Mayo capsulodesis technique would create a reconstruction which could safely withstand 50 degrees flexion, and the 3-LT reconstruction seemed to tolerate up to 30 degrees. The lack of scar tissue might even replicate the situation directly after surgery, which might create opportunities for early active motion. We hypothesized that a controlled early rehabilitation with a limitation of wrist flexion might be possible.

The knowledge obtained in **Chapter 2, Chapter 3** and **Chapter 7** was intended to lead to a clinical trial that would test two post-operative rehabilitation protocols. However, multiple centers of the Xpert Clinic changed the standard postoperative regimen after 3-LT. In the new protocol, patients started mobilizing the wrist four weeks earlier. This change led to a multi-center cohort study comprising 108 patients that compared the results of both protocols (**Chapter 8**). It revealed that early active motion leads to non-inferior results in terms of PROMs, range of motion, grip strength and satisfaction with treatment, without more complications.[10] Based on these findings, **chapter 8** concluded that early active motion after 3-LT was considered safe.

As 'safety' can be considered to indicate the extreme end of the spectrum, i.e. no adverse consequences, a more nuanced conclusion might be warranted. The study was performed on a limited number of patients, and it was not powered on relatively rare complications such as failure of the reconstruction. To determine whether early active mobilization is scientifically safe, it is mandatory to perform a safety study with a larger sample size. However, performing such a study in this relatively rare pathology would be highly challenging. A balance in which advantages and disadvantages are weighted against each other might be more feasible. In **Chapter 8,** we did not observe any differences in rates of return to work and activities.

Based on the study results, we suggest that potential benefits of early active motion after treatment outweigh those of prolonged immobilization. More insight into return to activities and work, patient comfort, and costs are needed, and future studies should examine the effects of early active motion protocols.

Moreover, in addition to the two rehabilitation protocols that we tested; future studies should compare different rehabilitation protocols in a prospective comparative manner. Also, the results after 3-LT might be generalizable to capsulodesis techniques, but this assumption should be confirmed in a similar prospective comparative way.

As introduced earlier, the scapholunate ligament is sometimes referred to as the anterior cruciate ligament (ACL) of the wrist.[11] Both ligaments are intra-articular, both are associated with instability, and both resist tensile forces from a shearing movement, which suggests a degree of similarity. However, as the knee allows more movement between the femur and the tibia, necessitating the ACL to resist shear forces, the scapholunate ligament might have more in common with the Lisfranc ligament in its role of absorbing strain forces.[12,13] Nonetheless, in the context of rehabilitation, the developments for ACL injuries might serve as a model for the treatment of SL injuries.

In the 1960s, surgically treated anterior cruciate ligament injuries were followed by cast immobilization, non-weight bearing and delayed return to activities. The rehabilitation was regarded as difficult and was accompanied by joint stiffness.[14,15] After 1990, accelerated rehabilitation protocols became the standard, with immediate motion, early weight bearing and faster return to work or sports.[15,16] From this perspective, the post-surgical care of ACL reconstruction might be ahead of the scapholunate dysfunction rehabilitation, and therefore valuable insights could be gained from the advancements made in ACL rehabilitation.

In 2016, the Royal Dutch Society for Physical Therapy presented an evidence-based ACL rehabilitation statement that provides a framework for consideration.[17] Some of their recommendations might be adopted in the research on scapholunate dysfunction, such as the standardized measurement of preoperative PROMs, ROM, and grip strength. Additionally, it might be beneficial to implement exercises aimed to activate secondary stabilizers (ECRB and ECRL, FCR, FCU and ECU) before surgery. After surgery, patient outcomes could be enhanced with exercises reactivating secondary stabilizers, initiating controlled movements with limited flexion, a fast start of neuromuscular training and proper monitoring of psychological changes throughout the rehabilitation.

Adopting these recommendations in the rehabilitation after SL surgery might have several potential benefits. Standardized pre-operative assessments, such as measuring PROMs, ROM, and grip strength, can provide baseline data and help surgeons tailor the treatment to individual patient needs, which may potentially lead to better outcomes. By focusing on exercises that activate secondary stabilizers and neuromuscular training, patients may experience better wrist function. Early initiation of post-operative movement within controlled parameters may lead to faster recovery and might result in a faster return to activities of daily living and work. By closely monitoring patients during rehabilitation, healthcare providers can limit the risks of stiffness, of loss of ROM or grip strength, and of psychological barriers to recovery. Involving patients in their own rehabilitation by providing them with clear guidelines and goals for exercises may empower them to take an active role in their recovery process.

In conclusion, the outcomes of this research suggest that controlled early rehabilitation with restriction to wrist flexion might be feasible. Information should be gained on which factors related to pathology, patient, surgeon, and treatment are currently involved in treatment decisions, followed by a study that tests the validity of these parameters in a prospective way. Research is needed on the effects of early active motion in terms of return to activities and work, patient comfort, and costs.

The developments for ACL injury rehabilitation might serve as a model for rehabilitation of injuries of the SL ligament, and some of these insights could be adopted, which might potentially improve functional outcome and lead to faster recovery, reduced risk, and patient empowerment.

The SLAC paradigm

'It's during the storm that a sailing boat becomes unstable, after the storm it may be too late.'[18] This comparison was made with regard to scapholunate dysfunction. It pointed at the unstable window of opportunity for treatment, before ending in the shipwreck of scaphoid-lunate advanced collapse. The problem with this comparison is that not every storm steers an unstable boat toward a fate becoming the next Titanic. In this part of the discussion, we shed light on the natural course of SL injuries and the treatment of combined injuries.

As noted in **Chapter 9,** SL injuries accompany distal radius fractures. Previous studies reported rates ranging from 4 to 13% visible on plain radiographs or CT scans, with some studies even suggesting 50 to 54% when arthroscopy was performed.[19–22] Our study, in which fluoroscopy was performed after reduction and fixation of a distal radius fracture without immobilization, found an incidence of scapholunate dissociation (static and dynamic) of 27%. PROMs did not differ between patients with and without SL injury after one year. This finding is in accordance with the results of Forward *et al.* 2007, who reported similar PROMs and VAS scores at one year follow-up.[23]

A subsequent, long-term (15 years) follow-up study by Mrkonjic *et al.* 2015 found no major clinical differences between patients with grade 1, 2 or 3 lesions. However, the study group was small (n=38), and no high-grade lesions were included.[24] The study in **Chapter 9** was not able to report patients with a SLAC wrist, probably due to the follow-up time of 1 year.

The SLAC pattern was initially documented in the famous study of Watson and Ballet, which was published in 1984 and which, at the time this thesis was written, had over 1100 citations. In their study, the authors analyzed more than 4000 radiographs and documented this typical pattern.[25] The paradigm of the development of SLAC is that it starts with a single traumatic injury or rupture of the SL ligament, followed by or combined with attenuation of secondary supporting ligaments, which may lead to postural deformities and scapholunate instability. Eventually, this process develops towards the typical collapse and arthritic changes of the wrist.

However, it is crucial to keep in mind that no study has ever documented the fundamental association between an injury of the SL ligament, or any other ligament pathology, and the onset of a SLAC wrist. This lack of association constitutes an important and critical deficiency in literature.

While it would be logical to infer that traumatic wrist ligament injuries can result in carpal motion dysfunction and instability, eventually leading to osteoarthritis,

the reverse can also be deduced: that wrist osteoarthritis, of unknown origin, may lead to attenuation in wrist ligaments. Patients might say that they fell on their painful wrist at some point in the years before their visit to the outpatient clinic. In other words, it is not clear whether wrist osteoarthritis is the result of a traumatic ligament injury or whether wrist osteoarthritis combined with ligament attenuation is a natural phenomenon which does not always result in scapholunate dysfunction.

In support of the latter assumption, some large postmortem human specimen studies showed that SLIL ligament injuries were frequently observed (in 28 to 35%) and were not always accompanied by osteoarthritis.[26,27] Clearly, shortcomings of these studies are the use of specimen, the impossibility to obtain a medical history (were these humans symptomatic?), and the absence of information about secondary stabilizers.

Another retrospective study radiographically compared symptomatic wrists with the asymptomatic contralateral wrist of the same patient and found pathological measures in the symptomatic side in more than 80% if the patients. Interestingly, on the asymptomatic side, 52% to 70% of the radiological measurements also were pathologic. About half the patients showed some arthritic changes on the symptomatic side, whereas less than a third showed changes on the asymptomatic side.[28] Half of the patients were unable to recall a specific injury. This finding indicates that scapholunate dissociation and osteoarthritis occur in asymptomatic wrists. Again, the progression of these asymptomatic lesions is unknown.

Another study reported follow-up findings on eleven symptomatic patients without radiological changes but with arthroscopically identified SL ligament lesions grade I and II who had declined further treatment. After a mean of seven years, these patients continued to have pain and functional limitations but no evidence of progression into an SLAC wrist.[29]

The results of the study reported in **Chapter 9,** along with the absence of data that explicitly prove scapholunate dissociation to be a precursor of SLAC and the relatively favorable outcome after non-surgically treated low-grade lesions at short-term and longer-term follow-up, raise questions about the fundamentals of the SLAC paradigm. Perhaps we need to consider the possibility of being overly reliant on past misconceptions. At least, more knowledge is needed to support the fundamentals of scapholunate dysfunction. Therefore, future research should examine the association and, even better, the causality between scapholunate dysfunction and SLAC.

Our study found that concomitant dynamic scapholunate injuries in surgically treated distal radius fractures do not require immediate surgical treatment, and that concomitant dynamic scapholunate injuries do not need to be immobilized after surgically treated distal radius fractures.[30] In the absence of an association between scapholunate dissociation and SLAC, surgeons might consider a 'wait and see' policy in case of asymptomatic static scapholunate dissociation.

To obtain more knowledge on the natural course of SL lesions, a study with long-term follow-up would be needed that randomizes surgical treatment versus no treatment for SL ruptures. However, such a study would probably be considered unethical. Within our study group, we are performing the KLAP study to follow the natural course of patients with hand and wrist pain in the outpatient clinic. A subgroup analysis on patients with SL lesions would possibly provide more information about the natural course of SL pathology.

In conclusion, future research should reassess the association and, even better, the causality between scapholunate dysfunction and SLAC. Concomitant dynamic scapholunate injuries in surgically treated distal radius fractures do not require immediate surgical treatment, and it is not necessary to immobilize concomitant dynamic scapholunate injuries after surgically treated distal radius fractures. In the absence of a proven association between scapholunate dissociation and SLAC, surgeons might consider a 'wait and see' policy in patients with asymptomatic static scapholunate dissociation.

Dealing with uncertainty

"Certainty is the illusion of knowing, and it's the enemy of discovery."[31] In this final chapter of the general discussion, we address the diagnostics, the treatment recommendations and the available patient information on SL dysfunction.

The process of diagnosing scapholunate dysfunction involves a detailed medical history, physical examination, and imaging.[32] Imaging generally starts with conventional radiographs in at least two directions and a clenched fist view. Sometimes, radiographs are followed by fluoroscopy, CT or MRI.[32,33] As many surgeons consider the specificity or sensitivity of the imagingnot to be high enough, most rely on arthroscopy as the golden standard for evaluating scapholunate dysfunction.[34]

In **Chapter 4,** 77 surgeons across the world were provided with identical videos of diagnostic radiocarpal and midcarpal arthroscopy. We found that the interobserver agreement in diagnosing and grading SL pathology was slight, independently of surgeon-specific factors.[35] Furthermore, consulting the arthroscopy images led to

more, and more invasive, surgery than patient information alone. These results were in line with the outcomes of the experiment reported in **Chapter 5,** which showed that the addition of midcarpal arthroscopy to radiocarpal arthroscopy alone did not improve the interobserver agreement. However, it did result in worse pathology grades and more recommendations for surgery, which was also more likely to be more invasive.[36] These results are consistent with previous research which showed that more sophisticated imaging has little influence on reliability.[37]

Despite the possibility that arthroscopy may provide useful information which may lead to correct diagnoses and to interventions that improve health; we must also consider that diagnostic surgery exposes patients to a combination of iatrogenic harm, debatable diagnoses, and unhelpful reconstructive surgeries that can harm their health and performance.

Performing reconstructive surgery after diagnostic surgery might also be influenced by various factors, such as opinions about the pathology and its treatment as well as cognitive bias, i.e., the mind's systematic interpretation tendencies to simplify information. The addition of midcarpal arthroscopy might also lead to confirmation bias, i.e., the tendency to search and interpret information in favor of prior beliefs and values.

We lack data that explicitly identify scapholunate dysfunction as a precursor of SLAC, and there are studies that report non-surgically treated low-grade scapholunate injuries without the onset of SLAC. These observations, along with the fact that diagnostic arthroscopy has low interobserver agreement and that adding more diagnostic information does not improve agreement bus does increase the likelihood of more invasive surgeries, underscore the need for a reevaluation of what conditions warrant surgical treatment. At the physician level, proper indications for diagnostic and reconstructive surgery are crucial. To make diagnostics easier, healthcare providers should no longer use debatable stadia in the scapholunate spectrum such as pre-dynamic 'instability', which is not objectifiable with diagnostic tests. Surgeons should not offer diagnostic wrist surgery to patients with non-objectifiable injuries but provide support to cope with their symptoms.

In **Chapter 4,** we found that the factors which had the strongest influence on the recommendation for surgery were the symptom intensity and the magnitude of activity limitations. This finding probably reflects the surgeons' tendency to treat symptoms.[35]

There is evidence of the notable influence of thoughts, emotions, and circumstances on human illness (the biopsychosocial paradigm of human illness behavior) and of

the relative lack of correspondence between symptoms and objective pathology (as assumed in the biomedical model). More intense symptoms and relative incapability can alert musculoskeletal specialists to look for common misconceptions about symptoms as well as for notable symptoms of stress and distress.

Hand surgeons might need to focus on how some patients accommodate with a wrist injury and why others do not. In this regard, the use of measurements of psychological factors, such as depression scales and the pain catastrophizing scale, in patients with hand and wrist conditions might increase the knowledge on how patients are coping with symptoms.[38–41]

To improve patient's expectations, it is important to consider how patient information is provided. In **chapter 6,** we studied the quality of online information for scapholunate dysfunction, assessed the readability and studied underlying dominant tones. We found that the quality was 'fair' quality and that 11% of the information was only about operative treatment, while operative and non-operative treatments were discussed in 82% of the information.[42]

On most of the examined websites, the complexity of the information exceeded the recommended reading levels. None of the websites that address scapholunate dysfunction met the standards for readability for readers with fewer than 6 years of education on all readability tools, as advised by the United States National Institution of Health and the American Medical Association. The limited quality of the provided information and the difficulty to read the information might lead to misunderstandings and misconceptions.

A dominant tone of fear correlated with texts that were difficult to read, and a dominantly tentative tone correlated with texts that were easier to read. Our findings showed that websites vary in word choice and concepts, which might also affect their readers' beliefs about their illness, their experience of symptom intensity, and the magnitude of their limitations. Word choice and the emotional tone of a text could influence a patient's attitude and expectations toward an illness and its treatment options.[43] However, little is known about the influence of sentiments in online information.

Professional societies must put efforts into providing appealing, readable information about SL ligament dysfunction on the internet.[44] They might also consider providing reliable and readable information that patients can read before visiting their physician. Alternatively, they might provide patients with decision aids, which have been shown to improve patient knowledge.[45] Suitable information in combination with a decision aid might improve a patient's understanding of the underlying pathology and might help patients to cope with uncertainty.

In conclusion, surgeons must be aware that a decision for diagnostic wrist arthroscopy results in more recommendations for reconstructive surgery, even though what is visible on arthroscopy may be unreliably interpreted. Secondly, surgeons must anticipate that notable symptom intensity and the magnitude of activity intolerance may be influenced by common misconceptions, and they should employ communication strategies that can help guide patients to a more accurate understanding of their condition. Thirdly, hand surgeons should investigate how people cope with injuries or symptoms and why others do not, and professional societies must strive to offer appealing, readable information about Scapholunate dysfunction on the internet or provide patients with a decision aid. Finally, clinicians should no longer use the term 'pre-dynamic instability' since it is a debatable stadium in the scapholunate spectrum, which is not objectifiable with diagnostic tests, and surgeons should not consider offering diagnostic wrist surgery to patients with non-objectifiable injuries but support them to cope with their symptoms.

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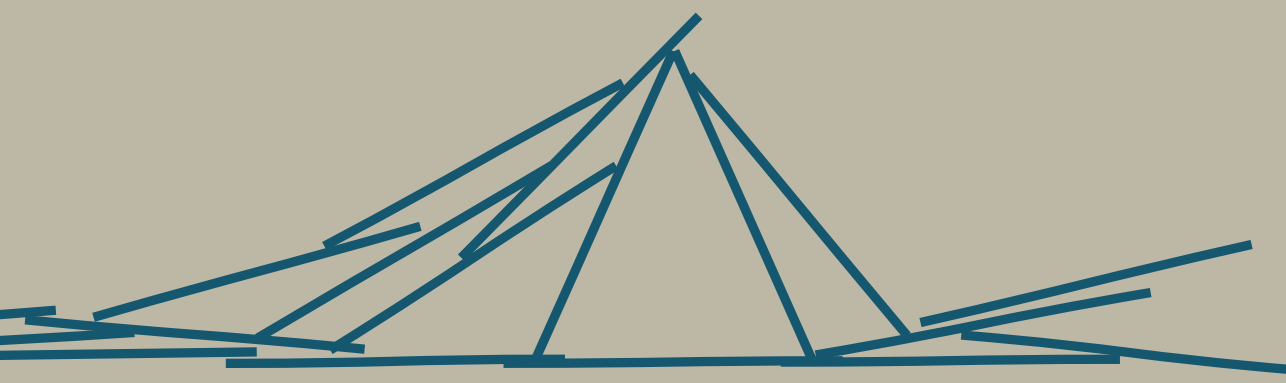
11 Summary



Summary

This thesis contains the results of studies performed to obtain more insight in biomechanics, diagnosis and treatment for scapholunate interosseous ligament (SLIL) injuries.

Part I

In part I, the wrist biomechanics after two common surgical procedures for scapholunate dysfunction were studied.

Chapter 2 reported wrist biomechanics after capsulodesis. In maximal flexion, the dorsal intercarpal reconstruction showed a mean elongation of 0.8 mm. No failure of the dorsal intercarpal reconstruction was observed. The dorsal intercarpal complex (DIC) showed an elongation of 3.9 mm. when the wrist was flexed maximally. In four arms sutures connecting the dorsal intercarpal complex to the surrounding tissue loosened between 55 and 60 degrees.

Chapter 3 examined elongation in relation to flexion, and type of failure after a 3-Ligament tenodesis (3LT). At 80° flexion, mean elongation of the flexor carpi radialis (FCR) tendon slip was 0.96 ± 0.38 mm. Mean elongation of the DIC was 3.75 ± 0.91 mm. at 80° flexion. Relative elongation of the FCR tendon slip was 4.1% and 33.4% of the DIC. In two tests (4%), sutures loosened at the proximal side of the DIC after 30° flexion. Ruptures of the radiotriquetral ligament, pull-outs of the bone anchor or FCR tendon ruptures were not observed.

The experiments suggested that the capsulodesis technique creates a reconstruction which can withstand 55 degrees flexion, and the 3-LT reconstruction tolerates up to 30 degrees without failure.

Part II

Given the limited reliability and accuracy of imaging, many surgeons consider wrist arthroscopy to be important for the diagnosis of SLIL pathology.

In **Chapter 4**, the influence of diagnostic arthroscopy on treatment recommendations and reliability of the arthroscopic classification for SLIL pathology was studied in a survey-based experiment. Seventy-seven surgeons evaluated scenarios of patients with wrist pain and a variation in symptoms, scaphoid shift test, time since onset of symptoms, and MRI appearance of the SLIL. Participants were randomized to view or not to view diagnostic wrist arthroscopy, and all surgeons viewing arthroscopic videos were asked to grade the SLIL pathology. The interobserver reliability of grading SLIL injury severity was none to slight (κ=0.18; 95% CI, 0.11 – 0.26). Diagnostic arthroscopy led to more recommendations for surgery (OR 6.9; 95% CI, 2.8 – 18; P<0.001), and more invasive surgery (RR 2.4; 95% CI, 1.3 – 4.2; P=0.004).

In **Chapter 5**, the addition of midcarpal arthroscopy versus radiocarpal arthroscopy alone was evaluated. Fourteen consecutive videos of diagnostic radiocarpal and midcarpal wrist arthroscopy for suspected SLIL pathology were selected. Sixty international surgeons were asked to grade the severity of SLIL pathology and to recommend surgical or nonsurgical treatment. The interobserver agreement for the Geissler classification was slight/fair for observers who reviewed midcarpal and radiocarpal videos (κ=0.21 [fair]; 95% CI, 0.10 – 0.32) and none to slight for those who viewed radiocarpal videos only (κ=0.18 [slight]; 95% CI, 0.076 – 0.28). Viewing midcarpal videos was associated with higher pathology grades, more recommendations for surgery, and a preference for tenodesis over scapholunate ligament repair.

In **Chapter 6**, online information for patients about SLIL dysfunction was assessed. Online information quality was measured using DISCERN, readability was measured using Simple Measure of Gobbledygook (SMOG; reflects how many years of education a person needs to understand a text), and present dominant tones in text were measured using the IBM Watson Tone Analyzer. The online information regarding SLIL dysfunction was of generally low quality, with limited readability (SMOG: 10 ± 1.9). None of the websites addressing SL dysfunction met standards for readability with fewer than 6 years of education. A dominant tone of fear correlated with difficult to read texts (r=1.0, P=0.015), a dominant tentative tone (r=-0.44, P=0.0034) with easier texts.

Part III

In **Chapter 7**, of this thesis, a systematic review provided an overview of postoperative immobilization protocols for surgically treated scapholunate ligament injuries and reported their impact on patient-reported outcomes. Fifteen studies involving 533 patients were included. Most patients (82%) underwent tenodesis, 18% underwent capsulodesis. The executed techniques varied widely. Immobilization varied from 2 to 8 weeks. No differences were observed between short (≤6 weeks) and long (>6 weeks) immobilization in terms of PROMs, pain, range of motion, grip strength or complications.

In **Chapter 8**, a multicenter cohort study was performed to investigate whether early active motion was noninferior to late active motion after 3-ligament tenodesis.

This study compared a late active motion protocol (immobilization for 10-16 days, starting wrist therapy in week 5-6) with an early active motion protocol (immobilization for 3-5 days, starting wrist therapy in week 2). A total 108 of patients were included. Patient-Reported Wrist/Hand Evaluation (PRWHE, P=0.35) and pain during physical load (P=0.85) following an early active motion protocol

were non-inferior compared to a late active motion protocol. Furthermore, it did not lead to more complications (P=0.54), differences in range of motion, grip strength (P=0.65) or less satisfaction with the treatment result (P=0.36). Earlier return to activities was not observed.

In **Chapter 9**, a prospective multicenter cohort study was performed to examine whether patients with a distal radius fracture and distal radioulnar joint (DRUJ) instability or scapholunate dissociation (SLD) have different reported outcome measures after 1 year. The primary outcome was the PRWHE at 6 and 12 months after surgery for the distal radius fracture. Out of 62 patients, 58% had intraoperative distal radioulnar joint instability and 27% scapholunate dissociation. No significant differences were found in patient-reported scores at follow-up between patients with stable and unstable distal radioulnar joints, nor between patients with and without scapholunate dissociation. Sixty-three percent of patients with an unstable distal radioulnar joint during surgery were stable when tested again after 6 months.

Appendices

Samenvatting

Dit proefschrift bevat de resultaten van studies die zijn uitgevoerd om meer inzicht te krijgen in de biomechanica, het diagnosticeren en de behandeling van letsels van het ligamentum Scapholunatum (SL-ligament).

DEEL I

De biomechanica van de pols werd onderzocht na twee veelvoorkomende chirurgische procedures voor SL-dysfunctie.

Hoofdstuk 2 onderzocht de biomechanica na capsulodese. Bij maximale pols flexie toonde de dorsale intercarpale reconstructie een gemiddelde rek van 0,8 mm. Er werd geen falen van de dorsale intercarpale reconstructie waargenomen. Het dorsale intercarpale complex (DIC) vertoonde een rek van 3,9 mm. bij maximale flexie. In 4 tests raakte de hechtingen die het dorsale intercarpale complex met het omringende weefsel verbond los tussen 55 en 60 graden flexie.

Hoofdstuk 3 onderzocht rek in relatie tot flexie en het type falen na een 3-Ligament Tenodese (3LT) procedure. Bij 80° flexie was de gemiddelde verlenging van de m. flexor carpi radialis (FCR) 0,96 ± 0,38 mm. De gemiddelde rek op het DIC was 3,75 ± 0,91 mm. bij 80° flexie. De relatieve verlenging van de FCR-peesslip was 4,1% en 33,4% van het DIC. In twee tests (4%) verslapten de hechtingen aan de proximale zijde van het DIC na 30° flexie. Falen van het radiotriquetral ligament, losraken van het botanker of FCR-peesscheuren werden niet waargenomen.

De experimenten suggereerde dat de capsulodese techniek een reconstructie creëert die 55 graden flexie kan weerstaan, en de 3-LT techniek een tot 30 graden.

DEEL II

Gezien de beperkte nauwkeurigheid van conventionele beeldvorming (röntgenfoto's, CT en MRI), beschouwen veel chirurgen polsarthroscopie als de gouden standaard voor de diagnose van SL-pathologie.

In **Hoofdstuk 4** werd de betrouwbaarheid van de arthroscopische classificatie voor SL-pathologie en de invloed van een diagnostische arthroscopie op behandeladviezen bestudeerd. Zevenenzeventig chirurgen evalueerden scenario's van patiënten met variabele klachten van de pols. De deelnemers werden gerandomiseerd om wel of niet beelden van een diagnostische polsarthroscopie te bekijken. Alle chirurgen die arthroscopische video's bekeken, werd gevraagd de SL-pathologie te graderen volgens de Geissler-classificatie. De betrouwbaarheid van het beoordelen van SL-letsel was gering (κ=0.18; 95% CI, 0.11 – 0.26). Diagnostische arthroscopie leidde tot meer aanbevelingen voor chirurgie (OR 6.9; 95% CI, 2.8 – 18; *P*<0.001), en meer invasieve chirurgie (RR 2.4; 95% CI, 1.3 – 4.2; *P*=0.004).

In **Hoofdstuk 5** werd de toevoeging van midcarpale arthroscopie ten opzichte van alleen radiocarpale arthroscopie geëvalueerd. Veertien opeenvolgende video's van diagnostische radiocarpale en midcarpale polsarthroscopieen werden geselecteerd. Een panel van 60 internationale chirurgen werden gevraagd om de letsels te graderen volgens de Geissler-classificatie en om een behandeling aan te bevelen. De overeenstemming voor de Geissler-classificatie was gering tot redelijk voor waarnemers die zowel midcarpale en radiocarpale video's beoordeelden (κ=0.21 [redelijk]; 95% CI, 0.10 – 0.32) en geen tot gering voor degenen die alleen radiocarpale video's bekeken (κ=0.18 [gering]; 95% CI, 0.076 – 0.28). Het bekijken van midcarpale video's werd geassocieerd met een hogere pathologie graad, meer aanbevelingen voor chirurgie en een voorkeur voor een tenodese ten opzichte van een direct herstel van het SL-ligament.

In **Hoofdstuk 6** werd online patiënten informatie over SL-letsel beoordeeld. De kwaliteit van de informatie werd gemeten met DISCERN, de leesbaarheid met de Simple Measure of Gobbledygook (SMOG, wat reflecteert hoeveel jaar onderwijs een persoon moet hebben genoten om een tekst te begrijpen), en onderliggende dominante tonen werden gemeten met de IBM Watson Tone Analyzer. Online-informatie over SL-letsel was over het algemeen van lage kwaliteit, met beperkte leesbaarheid (SMOG: 10 ± 1,9). Geen van de websites die SL-letsel behandelden, voldeed aan de leesbaarheidsnormen van minder dan 6 jaar onderwijs. Een toon van 'angst' correleerde met moeilijk leesbare teksten (r=1.0, P=0.015), een dominante 'voorzichtige' toon (r=-0.44, P=0.0034) met gemakkelijker leesbare teksten.

DEEL III

In **Hoofdstuk 7** werd een systematisch literatuuronderzoek uitgevoerd om een overzicht te verkrijgen van immobilisatieprotocollen na chirurgisch behandelde SL-letsels en de impact op patiënt-gerapporteerde uitkomsten (PROM). Deze studie omvatte 15 studies met in totaal 533 patiënten. De meeste patiënten (82%) ondergingen een tenodese, 18% onderging een capsulodese. De uitgevoerde technieken varieerden sterk. Immobilisatie varieerde van 2 tot 8 weken. Er werden geen verschillen waargenomen tussen korte (≤6 weken) en lange (>6 weken) immobilisatie in PROM's, pijn, bewegingsbereik, knijpkracht of complicaties.

In **Hoofdstuk 8** werd een cohortonderzoek uitgevoerd om te bestuderen of vroeg actieve beweging niet inferieur is aan laat actieve beweging na 3-LT. Deze studie vergeleek een laat actief bewegingsprotocol (immobilisatie voor 10-16 dagen, starten met fysiotherapie in week 5-6) met een vroeg actief bewegingsprotocol (immobilisatie voor 3-5 dagen, starten met fysiotherapie in week 2). In totaal werden 108 patiënten bestudeerd. Patiënt-gerapporteerde pols/hand evaluatie (PRWHE, P=0.35) en pijn tijdens belasten van de pols (P=0.85) na een vroeg actief

bewegingsprotocol waren niet inferieur aan een laat actief bewegingsprotocol. Bovendien leidde het niet tot een toename van complicaties (*P*=0.54), verschillen in bewegelijkheid van de pols, knijpkracht (*P*=0.65) of tot minder tevredenheid met het behandelresultaat (*P*=0.36). In deze studie werd eerder kunnen herstarten van activiteiten (werk/hobby's) niet waargenomen.

In **Hoofdstuk 9** werd een cohortonderzoek uitgevoerd om te onderzoeken of patiënten met een distale radius fractuur en distale radioulnair gewricht (DRUJ) instabiliteit of Scapholunaire dissociatie (SLD) verschillende uitkomsten hebben in patiënt-gerapporteerde uitkomstmaten na 1 jaar. Na 6 en 12 maanden na fixatie van de distale radius fractuur werd de PRWHE-vragenlijst afgenomen. Van de 62 patiënten had 58% tijdens de operatie DRUJ-instabiliteit en was er bij 27% sprake van SLD. Er werden geen significante verschillen gevonden in PRWHE bij follow-up tussen patiënten met stabiel danwel een instabiel DRUJ, noch tussen patiënten met of zonder SL-dissociatie. 63% van de patiënten met een instabiel DRUJ tijdens de operatie bleken na 6 maanden een stabiel DRUJ te hebben.

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This thesis

Bakker D, Oomen R, Colaris JW, Kleinrensink G-J, Verhofstad MHJ, Kraan GA, Mathijssen NMC. Optimizing recovery after scapholunate ligament surgery: similar results following short and long immobilization, a systematic review.
HAND. (SUBMITTED)

Bakker D, Merkens S, Colaris JW, Kleinrensink G-J, Mathijssen NMC, Kraan GA. Flexor Carpi Radialis and Dorsal Intercarpal Complex Elongation After 3 Ligament Tenodesis.
Journal of Hand Surgery European Volume. (SUBMITTED)

Bakker D, Derksen BM, Kramer S, Cleffken B, Schep, NWL, Concomitant ligament injuries can be left untreated during surgery of distal radial fractures.
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Bakker D, Kraan GA, Colaris JW, Mathijssen N, Ring D, Crijns TJ. Is Midcarpal Arthroscopy for Suspected Scapholunate Pathology Associated with Greater Interobserver Agreement and More Frequent Offer of Surgery?
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Outside this thesis

Bakker D, de Jong L, van Buijtenen J, Verseveld M. Traumatic inguinal hernia after fall from truck on a broom.
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Journal of Orthopaedics. 2020

PhD portfolio

PhD Student	D. Bakker
Promotores:	Prof. dr. M.H.J. Verhofstad Prof. dr. G. J. Kleinrensink
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PhD period:	2017-2025

PhD COURSES	**YEAR**	**ECTS**
Scientific Integrity	2024	0.3
Systematic literature review in PubMed	2018	0.4
LISA (Lowlands Institute of Surgical and Applied Anatomy)	2023-2024	1.5
CONFERENCES / PRESENTATIONS		
Orthopaedische Vereniging Najaarscongres, Veldhoven	2017	0.5
Federation of European Societies for Surgery of the Hand (FESSH), Copenhagen	2018	0.5
Federation of European Societies for Surgery of the Hand (FESSH), Rotterdam	2021	0.5
Chirurgendagen NvvH, den Haag	2022	0.5
Chirurgendagen NvvH, Veldhoven	2023	0.5
Chirurgendagen NvvH, Veldhoven	2024	0.5
TEACHING		
Anatomy courses for medical students	2017-2021	3.0
Training staff Ministry of Defense	2024	1.0
Training medical interns	2021-2024	1.0
OTHER		
Research Internship, University of Texas at Austin, Texas, USA	2017-2018	3.0
Research meetings, ‘de Rode Hand’, Erasmus MC	2019	1.0
Research meetings, Orthopedie, Reinier de Graaf Ziekenhuis	2019-2024	1.5
Research meetings, Traumachirurgie, Erasmus MC	2022-2024	1.0
CASH cursorisch onderwijs AIOS Heelkunde	2021-2024	3.0
Supervising master student		2.0
TOTAL		**21.7**

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Curriculum vitae

Daniël Bakker was born on February 12, 1993, in Hilversum, the Netherlands. After graduating from Comenius College in 2011, he pursued Neuroscience at the University of Amsterdam. In 2012, he transitioned to medical school at Erasmus University Rotterdam.

During his bachelor's and master's studies, he actively participated in teaching anatomy at the Anatomy Department of Erasmus University Medical Center. He was also involved in extra-curricular anatomy education (EARP). Additionally, he began conducting research at the Department of Orthopedic Surgery at Reinier de Graaf Gasthuis in Delft, under the mentorship of dr. Gerald Kraan, dr. Nina Mathijssen and prof. dr. Gert-Jan Kleinrensink.

In 2017, Daniël moved to Austin, Texas, USA, for a research internship led by prof. dr. David Ring. After earning his medical degree in 2020, he started his residency at the Department of Surgery at Maasstad Hospital, under the guidance of drs. Rene Klaassen and dr. Bram Fioole. A year later, he began his surgical training at both the Department of Surgery at Reinier de Graaf Gasthuis (mentored by dr. Daphne Roos) and the Department of Surgery at Erasmus University Medical Center (mentored by dr. Sjoerd Lagarde and prof. dr. Bas Wijnhoven).

Beyond his medical training, Daniël is a co-founder of Anapptomy, a platform that focuses on teaching surgical anatomy. He also assists the medical staff at football club NAC Breda and serves as a board member of the Dutch Society of Trauma Care.