Diagnosing carpal instabilities using wrist cineradiography

Sulkers, G.S.I.

Publication date
2020

Document Version
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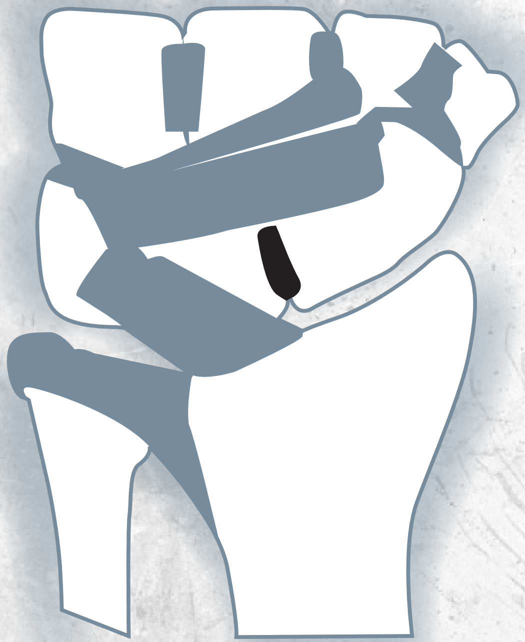

George Siauw In Sulkers

DIAGNOSING CARPAL INSTABILITIES USING WRIST CINERADIOGRAPHY

George Siauw In Sulkers

ISBN: 978-94-93197-26-8

Cover, layout and printing: Off Page, Amsterdam

DIAGNOSING CARPAL INSTABILITIES USING WRIST CINERADIOGRAPHY

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad van doctor

aan de Universiteit van Amsterdam

op gezag van de Rector Magnificus

prof. dr. ir. K.I.J. Maex

ten overstaan van een door het College voor Promoties ingestelde commissie,

in het openbaar te verdedigen in de Agnietenkapel

op vrijdag 16 oktober 2020, te 14.00 uur

door George Siauw In Sulkers

geboren te Amsterdam

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The research and published articles described in this thesis are not subjected to any form of funding

The wrist is the “keystone” of the hand – Bunnel

CHAPTER 1

GENERAL INTRODUCTION

Carpal instability is related to ruptured or lax carpal ligaments and may lead to chronic pain and degenerative changes of the wrist. Carpal instabilities can be classified as carpal instability dissociative (CID), carpal instability non-dissociative (CIND) or carpal instability combined or complex (CIC) (Garcia-Elias, 1997; Larsen et al., 1995; Lichtman et al., 1993; Lichtman and Wroten, 2006; Watson and Ballet, 1984; Wolfe et al., 2012; Wright et al., 1994).

A CIND describes an instability between the carpal rows and a CID is defined as an instability within the proximal or distal carpal row (Garcia-Elias et al., 1989; Larsen et al., 1995; Wright et al., 1994). The dissociation in the proximal carpal row can be divided into a scapholunate dissociation (SLD) and lunotriquetral dissociation (LTD). However, fractures or non-union of the bones in the proximal carpal row may lead to CID as well (Larsen et al., 1995; Mayfield et al., 1980; Ritt et al., 1998).

The scapholunate (SL) joint is the most examined joint in the wrist and the SL ligament is believed to be the key stabilizer of the wrist. Although, literature is controversial about the natural history of an untreated SLD, it is generally accepted that a SLD leads to chronic pain in the wrist and may lead to radio- and mid-carpal arthrosis. Therefore, early recognition and consequently treatment of a SLD may avoid a salvage procedure of the wrist (Chim and Moran, 2014; Lane et al., 2010; O'Meeghan et al., 2003; Watson and Ballet, 1984). Physical examination and conventional radiographs are essential in the primary work-up for diagnosing SLD. Positive findings, which are described below, suggest the presence of SLD. However, due to a low sensitivity of physical examination and conventional radiographs, additional imaging is essential when there is a clinical suspicion of a SLD (Marx et al., 1999; Megerle et al., 2011; Pliefke et al., 2008; Prosser et al., 2011).

Arkless described the role of wrist cineradiography for diagnosing SLD in 1966. Since then only a few studies compared wrist cineradiography with arthroscopy and/or arthrotomy for diagnosing SLD (Langner et al., 2015; Pliefke et al., 2008). Wrist cineradiography plays an important role in the early recognition of a SLD. Additionally cineradiography is useful for diagnosing other forms of carpal instability. The aim of this thesis is to validate wrist cineradiography for diagnosing SLD.

To maximize the use of wrist cineradiography, knowledge of normal carpal kinematics and the divergent carpal kinematics in patients with a SLD are essential and will be outlined below.

NORMAL CARPAL KINEMATICS

Wrist motions are classically defined in anatomic directions of flexion, extension, radial deviation and ulnar deviation. However, most activities performed with the hand involve wrist motions that simultaneously combine flexion or extension with radial or ulnar deviation, like circumduction or the dart throwing motion (Crisco et al., 2005; Moojen et al., 2003; Short et al., 2007). The movements of the carpal bones are highly complex due to the irregular size and shape of the multiple small articulating surfaces and the complex forces that cross the wrist. Most movement occur in the radiocarpal joint in where the distal carpal row can be considered as a single functional unit (Moojen et al., 2003; Patterson et al., 1997; Seradge et al., f1990).

The scaphoid, lunate and triquetrum are known as an intercalated segment as no tendons insert upon them (Linscheid et al., 1972; Seradge, 1990). Their motion is entirely passive and depends on their surrounding articulations, checked by intrinsic (or interosseous) and extrinsic carpal ligaments (Figure 1).

When the wrist flexes, mechanical forces of the distal carpal row drive the distal pole of the scaphoid into flexion, the lunate follows passively when the SL ligament is intact. Subsequently the triquetrum flexes as consequence of an intact lunotriquetral (LT) ligament. When the wrist extends the opposite movement will occur. The distal carpal row pushes the triquetrum in extension through the articulation between the hamate and triquetrum (Moojen et al., 2003). The triquetrum then pulls the rest of the proximal carpal row into extension through the LT and SL ligament.

During radial deviation the proximal carpal row flexes and slides ulnarly in a reciprocal relationship with the distal carpal row. The scaphoid flexes and pronates over the palmar radioscaphocapitate ligament. This motion is transmitted through the SL ligament,

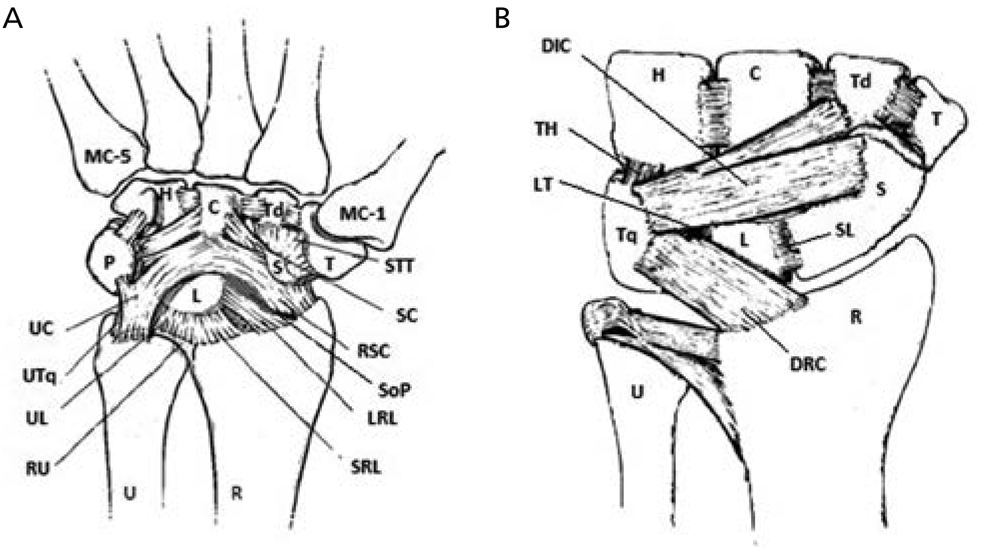

Figure 1. Intrinsic and extrinsic ligament of the wrist. A: Palmar view B: dorsal view C = capitate; DIC = dorsal intercarpal ligament; DRC = dorsal radiocarpal ligament; H = hamate; L = lunate; LRL = long radiolunate ligament; LT = lunotriquetral ligament; MC = metacarpal; P = pisiform; R = radius; RSC = radioscaphocapitate ligament; RU = palmar radioulnate ligament; S = scaphoid; SL = scapholunate ligament; SoP = Space of Poirier; SRL = short radiolunate ligament; STT = scaphotrapezial-trapezoid ligament; T = trapezium; Td = trapezoid; TH = triquetrohamate ligament; U = ulna; UC = ulnocapitate ligament; UL = ulnolunate ligament; UTq = ulnotriquetral ligament.

which will force the lunate to flex. This is followed by flexion of the triquetrum via the LT ligament.

During ulnar deviation the proximal carpal row extends. The lunate is forced to follow the triquetral motion and extends. Consequently, the scaphoid will be pushed in an extended and supinated position. Flexion and extension of the proximal carpal row during radial and ulnar deviation is also described as out-of-plane motion (Crisco et al., 2005; Moojen et al., 2003).

SCAPHOLUNATE DISSOCIATION (SLD)

Pathomechanics

The SL ligament is considered to be the primary stabilizer of the SL joint. Secondary stabilizers like the volar part of the radioscaphocapitate ligament, long and short radiolunate ligament, radioscapholunate ligament and the scaphotrapezial-trapezoid ligament may play an additional role in stabilizing the SL joint. Dorsally the radiotriquetral and dorsal intercarpal (DIC) ligament are considered as the secondary stabilizers of the SL joint (Figure 1). However, the relative importance of these secondary stabilizers is not definitely established yet (Chennagiri and Lindau, 2013; Kuo and Wolfe, 2008; Short et al., 2007).

SLD can be divided in predynamic (or occult), dynamic and static instability (Kuo and Wolfe, 2008; Watson et al., 1993).

1. Predynamic instability is the mildest form of SL instability. The SL ligament is partially ruptured. Positioning of the scaphoid and lunate are not disturbed unless the wrist will be exposed to motion or is mechanically loaded. It must be noted that a predynamic SLD not always develops into a dynamic SLD (Kuo and Wolfe, 2008; Watson et al., 1993).
2. It is considered that for a dynamic SLD the strongest part of the SL ligament (dorsal component) is ruptured with a partial injury of one or more secondary stabilizers. Again alignment of the scaphoid and lunate is undisturbed unless the wrist is subjected to motion or is mechanically loaded (Kuo and Wolfe, 2008; Watson et al., 1993).
3. Static SLD is defined as a complete rupture of the SL ligament in combination with a rupture or attenuation of one or more secondary stabilizers of the SL joint. In this stage, the scaphoid and lunate are dissociated from each other. The scaphoid will move to an abnormal flexed and pronated position and the lunate and triquetrum will tend to an abnormal extended position also known as a dorsal intercalated segment instability (DISI). Additionally the distal carpal row will be translated to a more dorsal and proximal position. During motion the lunate and triquetrum will move independently from the scaphoid (Kuo and Wolfe, 2008; Larsen et al., 1995; Mayfield et al., 1980; Watson et al., 1993). In time postural changes of the scaphoid, lunate and capitate become irreversible because of secondary

changes in most or all of the supporting ligaments. The altered kinematics and abnormal loading of the wrist may lead to progressive degenerative changes known as a scapholunate advanced collaps (SLAC) (Chim and Moran, 2014; Watson and Ballet, 1984).

Diagnostic workup

Conventional radiographs are classically useful for diagnosing a static SLD. Radiographs are considered positive for a static SLD when minimum one of the following is seen: widening of the SL distance (≥ 3 mm), increased SL angle (≥ 60°) or an increased RL angle (≥ 12°) (DISI) (Figure 2). Additionally the cortical ring sign whereby increased flexion of the scaphoid makes the waist of the scaphoid look like a ring, may be a sign of a static SLD. Finally, disruption of the first and second lines of Gilula is also a sign of a static SLD (Gilula et al., 2002; Pliefke et al., 2008). However, it must be noted that carpal instability is a dynamic entity, and therefore dynamic imaging is mandatory.

Wrist cineradiography is a real-time imaging modality which may play an important role for diagnosing a (dynamic) SLD. Wrist cineradiography is considered positive for a dynamic SLD if movement between the scaphoid and lunate bones is not synchronous and/or a diastasis between the two bones could be provoked (Pliefke et al., 2008). Additionally, when the lunate does not flex synchronously with the scaphoid and does not pass the 0° line of the RL angle during flexion of the wrist, a dynamic SLD is suspected (Short et al., 1995). Concerning a static SLD wrist cineradiography may be a useful tool to see if the malalignment of the carpal bones can be reduced by manipulating the wrist. Possible reduction of the carpal bones may influence the treatment strategy of a static SLD (Chennagiri and Lindau, 2013).

Management

Early diagnosis and treatment is important as this may have influence on the choice of treatment. Although a predynamic or occult SL instability may benefit from conservative

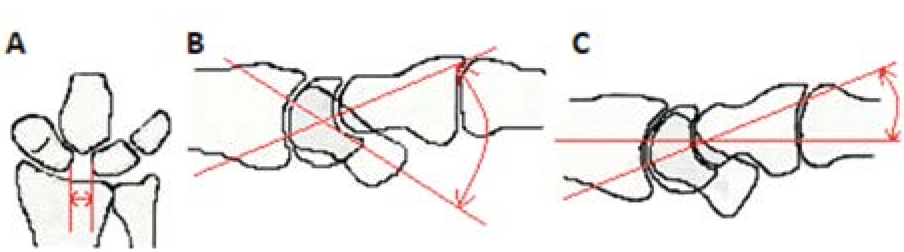

Figure 2. Measurements of the SL distance, SL angle and RL angle. A: Scapholunate diastasis is measured from the middle of the medial facet of the scaphoid and the lunate bones. B: The SL angle is measured by the tangent fitted to the volar border of the scaphoid and the lunate axis. C: The RL angle is measured by a line through the longitudinal axis of the radius and the lunate axis.

treatment with splinting and physiotherapy (Chennagiri and Lindau, 2013; Kuo and Wolfe, 2008; O'Meeghan et al., 2013). A dynamic SLD may be treated with a direct repair of the SL ligament in combination with K-wire fixation. In here, it is important that the remnants of the SL ligament are of good quality for a primary reconstruction. An undefined delay in diagnosis or treatment may impair the quality of the ruptured SL ligament, which consequently leads to a SL ligament which is not suitable for a primary reconstruction. Several reconstructive procedures have been attempted when the SL ligament is irreparable including capsulodesis, tenodesis consisting of a SL ligament reconstruction and various intercarpal fusions, all showing variable results (Athlani et al., 2018; Chennagiri and Lindau, 2013; Garcia-Elias et al., 2006; Kuo and Wolfe, 2008; Naqui et al., 2018).

The management of static SL instability remains controversial. Restoring the correct anatomy and biomechanics is considered to be important, because failure to do so may lead to arthritic changes in the wrist (Naqui et al., 2018; Watson et al., 1997). The outcome is largely dependent upon whether the carpal bones are reducible or not. Therefore, pre-operative knowledge about the reducibility of the carpal bones is mandatory. Not only a correct treatment plan can be made, but also patient outcome expectations can be managed.

Many procedures are described with effective results when the carpal bones are reducible, including tenodesis, capsulodesis, and (partial) carpal fusion (Athlani et al., 2018; Chennagiri and Lindau, 2013; Kuo and Wolfe, 2008; Naqui et al., 2018).

In case of a SLAC wrist more salvage procedures are recommended, like a proximal row carpectomy, partial wrist arthrodesis (e.g. four corner arthrodesis) or even a total wrist arthrodesis or wrist prosthesis (depending on the grade of arthrosis in the wrist) (Chim and Moran, 2014; Kuo and Wolfe, 2008).

A simple, non-invasive, cheap and reliable imaging modality is desirable for diagnosing SLD in an early stage as early treatment may affect treatment outcomes for patients with a SLD. Additionally, knowledge about the carpal kinematics in patients with a (static) SLD may predict treatment outcomes and patients' expectations. Wrist cineradiography may meet all of these expectations, and with this thesis we hope that we make a great contribution to the early diagnosis and subsequently treatment outcomes of a SLD.

AIMS AND OUTLINE OF THIS THESIS

The aim of this thesis is to validate wrist cineradiography for diagnosing SLD. Additionally, this thesis focusses on diagnosing other forms of carpal instability using wrist cineradiography. Finally, a pilot study evaluating a wrist exercise program for patients with palmar CIND was evaluated.

In **chapter 2** an outline of the different forms of CIND is given.

In **chapter 3** we created a protocol for diagnosing carpal instability using wrist cineradiography. With this protocol, we want to create uniformity in obtaining and assessing wrist cineradiography for diagnosing carpal instabilities.

The aim of **chapter 4** was to evaluate the diagnostic value of wrist cineradiography for diagnosing SLD. Also, the diagnostic value of conventional radiography was assessed for diagnosing SLD.

In **chapter 5** the diagnostic value of diagnosing SLD using wrist cineradiography was evaluated in a hospital with less experience in obtaining wrist cineradiographies. Second, the diagnostic value for diagnosing SLD using conventional radiographs was assessed. And finally, we tried to validate the prediction model which was obtained in chapter 3.

The purposes of **chapter 6** were to evaluate the inter- and intra-observer variability for diagnosing SLD using wrist cineradiography.

The aim of **chapter 7** was to evaluate a wrist exercise program which was developed in our institute for patients with a palmar CIND.

In **chapter 8** the findings presented in this thesis will be discussed including future perspectives in diagnosing carpal instability.

Dutch and English summaries of this thesis are presented in **chapter 9** and **chapter 10**.

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CHAPTER 2

CARPAL INSTABILITY NON-DISSOCIATIVE (CIND)

With the term "snapping wrist", Mouchet and Belot described a form of carpal instability for the first time in 1934. It was not until the 1970s that research about carpal instability evolved exponentially and different forms of carpal instability were described. Linscheid et al. described a form of midcarpal instability after malunited distal radius fractures in 1972. Since then many different forms with different terms are described for midcarpal instability.

As described in chapter 1, a carpal instability existing either at the radiocarpal or the midcarpal joint with an intact proximal and distal carpal row are defined as carpal instability non-dissociative (CIND) (Larsen et al., 1995; Wright et al., 1994). The relationship between the carpals in the same row are undisturbed. (Lichtman and Wroten, 2006; Wolfe et al., 2012). Nowadays, it is generally accepted that there are four major subcategories of CIND: palmar CIND, dorsal CIND, combined CIND and adaptive CIND. (Garcia-Elias, 1997; Larsen et al., 1995; Lichtman et al., 1993; Lichtman and Wroten, 2006; Wolfe et al., 2012; Wright et al., 1994).

Carpal instability must not be confused with hypermobility or laxity. Hypermobility or laxity refers, in biomechanical terms, to the inability of a joint to withstand physiological loads throughout its range of motion. Malalignment alone does not equate to instability. In clinical terms, instability refers to the symptoms a patient presents within a joint (e.g. giving way, pain) in combination with clinical signs of excessive or abnormal mobility on stressing the joint. The mere presence of excessive mobility in a joint should be termed hypermobility or laxity. Specifically, instability is a symptom in association with clinical signs. While laxity is a clinical finding without symptoms (Chennagiri and Lindau, 2013; Garcia-Elias, 1997).

PALMAR CIND

Palmar CIND, also referred as ulnar midcarpal instability or CIND-VISI (volar intercalated segment instability), is the most common form of CIND.

This form of CIND is first described as a true clinical syndrome by Lichtman et al. in 1981. He referred to this disorder as an ulnar midcarpal instability. In 1993, he renamed it to palmar CIND to distinguish it from an entity where the midcarpal subluxation appeared to be occurring in the dorsal direction (Lichtman et al., 1993).

Pathomechanics

Palmar CIND is implicated when an injury or laxity of the ulnar arm of the palmar arcuate (i.e. triquetral-hamate-capitate) ligament and/or the dorsal radiotriquetral ligament occurs. The head of the capitate and hamate sags into the midcarpal joint. The proximal carpal row flexes (VISI), which causes an associated volar translation of the distal carpal row. In this subluxated position the normal joint reactive forces cannot develop between the proximal and distal carpal row. Therefore a smooth transition of the proximal carpal row from flexion to extension during ulnar deviation does not occur. Flexion of the proximal carpal row remains until maximal ulnar deviation has been reached and the forces across the triquetrohamate joint are re-engaged. At that time a rapid catch-up clunck occurs when the proximal carpal row jumps from flexion into extension and the head of the capitate and hamate are relocated completely. These findings are based on cadaveric studies producing a VISI deformity (Lichtman et al., 1981; Lichtman et al., 1993; Lichtman and Wroten, 2006; Wolfe et al., 2012).

Clinical presentation

Patients presents with a painful and spontaneous clunck occurring with ulnar deviation and pronation of the wrist. Most patients do not recall a specific injury associated with the onset of the symptoms and a lot of patients has symptoms on both wrists, despite presentation with symptoms predominantly in one wrist. Generalized ligamentous laxity is a common finding in this population. With inspection, a volar sag at the midcarpal joint can be noted. Tenderness can be observed at the ulnar carpus with palpation, especially on the triquetrohamate joint and the ulnar support test may be positive (Lichtman et al., 1981; Lichtman and Wroten 2006; Wolfe et al., 2012). The classic test which is believed to be diagnostic for a palmar CIND is the midcarpal shift test. The wrist of the patient is placed in a neutral position with the forearm in pronation. The examiner passively translates the distal carpal row in a palmar direction, the wrist is then axially loaded and ulnarly deviated by the examiner. The test result is positive if a painful clunck occurs which reproduce the patient's symptoms (Lichtman et al., 1981; Wolfe et al., 2012).

Diagnostic workup

Routine radiographs may show a mild VISI pattern in the neutral position of the wrist but are mostly normal. Wrist cineradiography may be a helpful tool to diagnose a palmar CIND. Wrist cineradiography may show a widening of the scaphotrapezium-trapezoid joint in ulnar deviation or a widened triquetrohamate joint in radial deviation (Garcia-Elias, 2008; Wolfe et al., 2012). On the lateral view, rotation of the proximal carpal row from flexion to extension is not smoothly during radial and ulnar deviation of the wrist (Lichtman and Wroten, 2006). Provocative tests may be helpful diagnosing a palmar CIND using wrist cineradiography. During the anterior drawer test the distal carpal row is translated into a palmar direction, showing a widened scaphotrapezium-trapezoid joint and/or a palmarly directed capitolunate subluxation. However the midcarpal shift test remains the most useful test, also using wrist cineradiography (Garcia-Elias, 2008; Lichtman and Wroten, 2006; Wolfe et al., 2012).

Management

Initial management of a palmar CIND is nonsurgical. Our institute developed a wrist exercise program showing long term satisfactory results. The program aims to improve positioning, strengthening, and functional stabilization of the wrist during activities

(Videler et al., 1999). Other conservative treatment strategies consist of activity modification, isometric exercises, splinting and pain reduction using nonsteroidal anti-inflammatory drugs medication. A splint giving ulnar support in a dorsal direction often reduces the carpal sag along with the VISI position of the proximal carpal row (Lichtman et al., 1993; Lichtman and Wroten, 2006; Wolfe et al., 2012).

Surgical interventions have been proposed to augment or shorten the involved ligaments, but outcomes are often disappointing and unpredictable. Partial fusions of the midcarpal or radiocarpal joint has reasonable results but is inherent with a limited range of motion and may cause functional impairment. Therefore surgical treatment is only recommended when conservative treatment fails (Lichtman and Wroten 2006; Wolfe et al., 2012; Wright et al., 1994).

DORSAL CIND

A dorsal CIND is less common then a palmar CIND and encompasses the capitolunate instability pattern (CLIP) which was first described by Louis et al. in 1984. The chronic form of this CLIP is described by Johnson and Carrera in 1986 as a chronic capitolunate instability pattern (CCIP).

Pathomechanics

A CLIP is supposed after a combination of ruptures or laxity of the radiolunate ligaments, the dorsal capitolunate ligament complex, and the extrinsic stabilizers of the scaphoid (Louis et al., 1984). While it is believed that a CCIP originates from an attenuation of the palmar radio-capitate ligament (Johnson and Carrera, 1986). The assumption is made that an increased laxity or underdevelopment of the dorsal intercarpal (DIC) ligament and excessive laxity of the long radiolunate and the radioscaphocapitate ligaments (space of Poirier) are two major factors that contributes to dorsal CIND. Most likely, there's a combination of factors explaining this type of instability. Deficiency of these ligaments allows the capitate to subluxate dorsally when the proximal carpal row extends during ulnar deviation (Wolfe et al., 2012). Secondary to this dorsal subluxation of the capitate the clinical clunck occurs. This is why a dorsal CIND is also referred as a CIND-DISI (dorsal intercalated segment instability) (Lichtman et al., 1993; Lichtman and Wroten, 2006; Wolfe et al., 2012;).

Clinical presentation

Patients with dorsal CIND have complaints of pain and cluncking in the wrist, typically when grasping objects with the forearm in supination (Lichtman and Watson, 2006; Louis et al., 1984; Wolfe et al., 2012). In the chronic form (CCIP) weakness is observed beside the pain and cluncking. Patients may report a hyperextension injury, but it is not sure if this is causally related (Johnson and Carrera, 1986; Lichtman and Watson, 2006; Wolfe et al., 2012).

The dorsal capitate displacement stress test or posterior drawer test is useful for diagnosing a dorsal CIND. Dorsally directed pressure is applied by the examiner, while at the same time longitudinal traction to the wrist is applied. The test result is positive if a dorsal subluxation of the capitate from the lunate reproduces the patient's symptoms (Lichtman and Watson, 2006; Louis et al., 1984; Wolfe et al., 2012).

Diagnostic work-up

Conventional radiographs are not helpful in diagnosing dorsal CIND. With wrist cineradiography a dorsal subluxation of the capitate may be seen during extreme ulnar deviation of the wrist in the lateral view. Sometimes, this subluxation is accompanied with the clinical clunk. However the most helpful tool in diagnosing a dorsal CIND is applying the dorsal capitate displacement stress test in the lateral view using wrist cineradiography. The images will show a dorsal subluxation of the proximal carpal row and almost complete dorsal subluxation of the capitate from the lunate, in which the capitate may be brought beyond the dorsal lip of the lunate (Garcia-Elias, 2008; Lichtman and Wroten, 2006; White et al., 1984). The diagnosis of CLIP is made if instability at the capitolunate joint reproduces the patient's symptoms (Lichtman and Wroten, 2006; Louis et al., 1984).

Management

Similar to palmar CIND, conservative treatment has usually a good response. Conservative treatment consists of avoidance or modification of specific activities that exacerbate the symptoms (Lichtman and Wroten, 2006; Louis et al., 1984; Wolfe et al., 2012). However, long-term pain relieve may not be provided with conservative treatment alone (Lichtman and Wroten, 2006; Ono et al., 1996). Surgical management may consist of (partially) closing the space of Poirier in where the radioscaphocapitate and long radiolunate ligament will be sutured to each other. The lunate and capitate will be stabilized effectively with this procedure and pain may be reduced. However, loss of wrist extension is expected after this procedure (Johnson and Carrera, 1986; Lichtman and Wroten, 2006; Wolfe et al., 2012).

COMBINED CIND

Patients with combined CIND demonstrate symptoms of both palmar and dorsal CIND which is described first by Apergis et al. in 1996.

Pathomechanics

Laxity or attenuation of both the volar and dorsal carpal ligaments results in a combined CIND. Signs of a palmar CIND (flexion of the proximal carpal row with an associated volar translation of the distal carpal row) and a dorsal CIND (a combination of increased laxity of the DIC, long radiolunate and the radioscaphocapitate ligament) can be found in these patients. (Apergis, 1996; Lichtman and Wroten, 2006; Wolfe et al., 2012).

There may be a volar sagging of the head of the capitate and hamate into the midcarpal joint similar to palmar CIND. With radial deviation the proximal carpal row is flexed and ulnarly translated. When the wrist deviates ulnarly the proximal carpal row jumps from flexion into extension. Extremes of ulnar deviation may cause a dorsal subluxation of the capitate from the lunate (Apergis, 1996; Lichtman and Wroten, 2006; Wolfe et al., 2012).

Clinical presentation

Patients with combined CIND described symptoms of both palmar and dorsal CIND. They usually have chronic pain of the wrist, obscure numbness and reduced grip strength, irrespective of activities. Some patients may have a history of hyperextension injury of the wrist or present after playing sports that involve repetitive trauma (e.g. tennis, gymnastics). Physical examination may show symptoms of generalized laxity. With inspection, a volar sag of the carpus may be seen. Moving the wrist from radial to ulnar deviation a sudden clunk of the proximal carpal row may appear. Thereby the midcarpal shift test, the dorsal capitate displacement stress test and the anterior drawer test are frequently positive (Apergis, 1996; Lichtman and Wroten, 2006; Wolfe et al., 2012).

Diagnostic work-up

Conventional radiographs may show signs of a VISI. However, wrist cineradiography seemed to be the most useful tool diagnosing combined CIND. Moving the wrist from radial to ulnar deviation may show a sudden clunck in where the proximal carpal row jumps from flexion into extension. Additionally, positive provocation tests like the midcarpal shift test, the dorsal capitate displacement stress test and the anterior drawer test are frequently positive.

During the anterior drawer test the distal carpal row is translated into a palmar direction. The test result is positive when a palmar capitolunate subluxation is seen on the lateral view. Given the high incidence of generalized laxity, wrist cineradiography of both wrists is important (Apergis, 1996; Lichtman and Wroten, 2006; Wolfe et al., 2012).

Management

The first choice of treatment remains conservative treatment including activity modification. Although patients may not respond to conservative management as well as to an isolated palmar or dorsal CIND (Apergis, 1996; Garcia-Elias, 2008; Lichtman and Wroten, 2006; Wolfe et al., 2012). If conservative treatment fails, surgical management is justified. Surgical management may consist of (partially) closing the space of Poirier by reefing the long radiolunate and radioscaphocapitate ligament in combination with reefing of the triquetrocapitate with lunotriquetral ligament (Apergis, 1996). Alternatively, if soft tissue reconstructions fail, fusion of the radiolunate joint using a corticocancellous bone graft to maintain carpal height, shown to be promising. Stability is provided and the clunck will be eliminated without interfering motion of the wrist (Garcia-Elias, 2008). Preserving range of motion and function is important as most patients are young (Apergis, 1996; Lichtman and Wroten, 2006; Wolfe et al., 2012).

ADAPTIVE CIND

Adaptive CIND conditions are described by instability secondary to abnormalities that are extrinsic to the carpus. A midcarpal instability following a malunited distal radius fracture is the classic example of an adaptive CIND (Linscheid et al., 1972; Taleisnik and Watson, 1984).

Pathomechanics

In patients with a dorsally displaced distal radius fracture, the lunate can be rotated palmarly to compensate for the increased inclination of the distal radial joint surface. The capitate is then collinear with the lunate, but dorsal to the longitudinal axis of the radius.

Alternatively, the increased inclination of the distal radial joint surface will be compensated by relative flexion of the capitate, whereby the capitate is collinear with the radius, but dorsal to the longitudinal axis of the radius. It is believed that the volar carpal ligaments are less capable of inducing the physiologic shift of the proximal carpal row from flexion to extension as the wrist ulnarly deviates. The carpal ligaments are intact, but distances between their origins and insertions are decreased by the dorsal tilt of the malunited distal radius, compensatory extension of the proximal carpal row and flexion of the distal carpal row (figure 1).

The decreased distances and repetitive overload of the midcarpal joint results in ligaments that are incapable of preventing an excessive dorsal translation of the capitate (Lichtman and Wroten, 2006; Taleisnik and Watson, 1984; Wolfe et al., 2012).

Clinical presentation

Patients with adaptive CIND classically have a distal radius fracture in the history. They present with tenderness at the capitolunate and triquetrohamate joints. Some patients may present with a midcarpal subluxation producing a painful clunk at the triquetrohamate joint when the wrist is ulnarly deviated with the forearm in pronation (Lichtman and Wroten, 2006; Linscheid et al., 1972; Taleisnik and Watson, 1984; Wolfe et al., 2012).

Diagnostic work-up

Lateral radiographs may show signs of a dorsally displaced distal radius. In where the lunate can be rotated palmarly to compensate for the increased inclination of the distal radial joint surface. The capitate will be collinear with the lunate, but dorsal to the longitudinal axis of the radius. Alternatively, the increased inclination of the distal radial joint will be

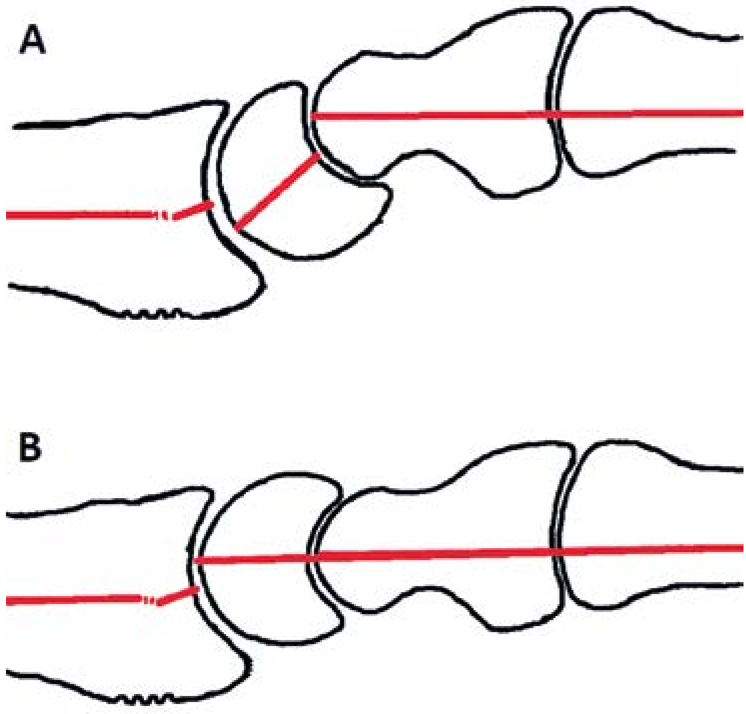

Figure 1. Adapative CIND. A. Patients with a dorsally displaced distal radius fracture have an increased inclination which can be compensated by a relative flexion of the capitate. In this the capitate is collinear with the radius, but dorsal to the longitudinal axis of the radius. B. Alternatively, the lunate can be rotated palmarly to compensate the increased inclination of the distal radial joint. The capitate is collinear with the lunate and dorsal of the longitudinal axis of the radius.

compensated by relative extension of the lunate and flexion of the capitate, whereby the capitate is collinear but dorsal to the longitudinal axis of the radius (figure 1).

Using wrist cineradiography, a subluxation of the capitate, which is painful, may be seen during ulnar deviation in the lateral views. In addition the lunate will extend during ulnar deviation, as in uninjured wrists, but with a marked reduction of normal palmar translation (Lichtman and Wroten, 2006; Taleisnik and Watson, 1984; Wolfe et al., 2012).

Management

Surgical management tends to be superior compared to conservative treatment. It consists of a corrective osteotomy of the distal radius to restore the dorsal tilt of the distal radius. Correction of the anatomy of the distal radius has the potential to realign the lunate and capitate with the longitudinal axis of the radius, thereby removing the compensative displacements of the lunate and capitate. The realignment of the bony anatomy rebalances the tension of the extrinsic ligaments, the capsule and the extrinsic muscle forces, thereby stabilizing the carpus. However, adaptive carpal malalignment may be corrected incompletely with a corrective osteotomy in chronic cases (Lichtman and Wroten, 2006; Taleisnik and Watson, 1984; Wolfe et al., 2012).

CARPAL INSTABILITY COMPLEX OR COMBINED (CIC)

A carpal instability characterized by derangement within (CID) and between (CIND) the carpal rows is defined as CIC. CIDs may become CICs due to a late sequela of isolated injury or additional injury involving the extrinsic support systems surrounding the CID lesion (Gilula et al., 2002; Larsen et al., 1995). The most frequent CIC is the perilunate dislocation, which refer to a lesser arc injury in where there is only a ligamentous injury. The most common greater arc injury is the transscaphoid perilunate dislocation (Mayfield et al., 1980). CIC also includes axial dislocation injuries, which usually demonstrates a dislocation component suggesting a rupture of both extrinsic and intrinsic ligaments (Garcia-Elias et al., 1989; Gilula et al., 2002). Altered pathomechanics, clinical presentation, diagnostic workup and management are depending on the type of CIC and falls out of the scope of this thesis.

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CHAPTER 3

WRIST CINERADIOGRAPHY: A PROTOCOL FOR DIAGNOSING CARPAL INSTABILITY

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The Journal of Hand Surgery, European Volume. 2018, 43: 174 – 178.

ABSTRACT

Carpal instability is often related to ruptured or lax carpal ligaments. Wrist cineradiography has been shown to be a good modality for diagnosing carpal instability. To create uniformity in obtaining and assessing wrist cineradiography, a wrist cineradiography protocol is desirable. This protocol will focus on wrist cineradiography for diagnosing carpal instabilities. It describes the pathologic motions of the carpus and correlates these with a clinical diagnosis.

INTRODUCTION

Carpal instability is often related to ruptured or lax ligaments (Garcia-Elias et al., 1995; Short et al., 2007; Watson and Ballet, 1984) and can be classified as: carpal instability dissociative (CID), carpal instability non-dissociative (CIND), and carpal instability combined or complex (Garcia-Elias, 1997; Lichtman and Wroten, 2006; Wolfe et al., 2012; Wright et al., 1994). The best known form of a CID is scapholunate dissociation (SLD), which is usually provoked by a fall onto the outstretched hand. It may also lead to radiocarpal and midcarpal osteoarthritis (O'Meeghan et al., 2003; Watson and Ballet, 1984). CIND describes a carpal instability between the carpal rows and is often caused by rupture of hyperlax carpal ligaments. Wrist cineradiography has been shown to be a good modality for diagnosing carpal instability (Langner et al., 2015; Pliefke et al., 2008; Sulkers et al., 2014a). To create uniformity in obtaining and assessing wrist cineradiography, a protocol is desirable. To this end, knowledge of normal carpal kinematics and the kinematics of the various patterns of carpal instability is crucial in the assessment of wrist cineradiography and has been extensively described.

This protocol will focus on wrist cineradiography for diagnosing carpal instabilities. It describes the pathologic motions of the carpus and correlates these with a clinical diagnosis.

WRIST CINERADIOGRAPHY

To obtain a wrist cineradiography a digital substraction angiography imager, a (mini) C-arm, or standard fluoroscopy with a minimum frequency of eight images per second is needed. Maximum radiation protection, including lead gloves, is advised to protect the examiner from radiation. It is important to familiarize the patient with the examination and to compare the injured wrist with the non-injured wrist; the non-injured wrist is always examined first (Appendix 1). The patient's arm is supported and held by the examiner.

Both postero-anterior (PA) and lateral views should be taken. To obtain the PA view, the patient's shoulder should be held in 90° of abduction and the elbow in 90° of flexion. The PA images should include a neutral view and views in radial and ulnar deviation. This is followed by the lateral views with the patient's upper arm alongside the body and the elbow in 90° of flexion. The lateral views should be taken in neutral, in flexion and extension, and in radial and ulnar deviation. While doing this, active wrist movements should be compared with passive ones. These movements may differ during active movement as the carpals are subject to different tension forces from the tendons, which have an additional stabilizing effect on the wrist during active motion (Milner, 2002). After obtaining the carpal movements, provocation tests are done while viewing the wrist, first in PA and then lateral projections (Appendix 1). A few provocation tests (e.g. Watson test) are not suitable for cineradiography, as the radiation protection gloves worn by the examiner block the field of view. It is important for the investigator to establish if the patient's complaints are due to a trauma, and differences between the wrists should be anticipated. If no injury is sustained, then the same findings (e.g. due to CIND) may be present in both the symptomatic and asymptomatic wrist.

PA view: neutral position

The radius and ulna must be projected next to each other. The styloid process of the radius must be seen as a single contour and the styloid process of the ulna must be projected most medially. The third metacarpal must be in line with the radius (Brink et al., 2010). The proximal border of the field of view should be just proximal to the distal radio-ulnar joint and the distal border at the proximal third of the metacarpals.

When in a neutral position, the carpals can be assessed the same way as in a conventional PA radiograph. Signs of a static SLD are a widened scapholunate (SL) distance (≥ 3 mm) and the cortical ring sign whereby increased flexion of the scaphoid makes the waist of the scaphoid look like a ring (Figure 1). Measurements can be performed from a Picture Archiving Communication System (PACS, Philips Medical Systems, Best, The Netherlands). With a digital ruler, the SL distance can be digitally measured, starting from the middle of the medial facet of the scaphoid to the lunate (Totty and Gilula, 1992). Also, if the lunate is extended, known as a dorsal intercalated segment instability (DISI), this is an indicator of static SLD. In this configuration, the lunate appears more triangular-shaped and is projected over the proximal pole of the capitate (Sulkers et al., 2014a). Finally, disruption of the first and second lines of Gilula is also a sign of a static SLD.

A displaced lunotriquetral junction and/or the lunate in a more flexed position (known as a volar intercalated segment instability (VISI)), are signs of a lunotriquetral dissociation or might be a sign of a radial-, ulnar-, or combined CIND. This can be recognized by a box-shaped lunate (Linn et al., 1990; Ritt et al., 1998).

Figure 1. Conventional radiography, PA view. Suspected static SLD.
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PA view: radial-ulnar deviation (RUD)

After the wrist has been examined in a neutral position, it is then actively moved to maximum radial deviation followed by maximum ulnar deviation under continuous fluoroscopy and within the limits of pain. To obtain a possibly increased range of motion, the examiner repeats these movements passively. This should be repeated until all movements of the carpal bones have been visualized and assessed. In a normal wrist, the proximal carpal row (PCR) will flex and extend during RUD and all movements within the PCR are synchronous (Video 1).

A dynamic SLD can only be seen during motion of the wrist and if there is no suspicion of static SLD in neutral position. If the movement between the scaphoid and lunate is not synchronous and a diastasis between the two bones can be provoked, then a dynamic SLD is suspected (Video 2). In this, the lunate moves partially with the scaphoid and the SL gap changes (Appendix 2). It is important to note that the gap between the scaphoid and lunate is usually not at its widest in extreme ulnar deviation. Moreover, in some cases, the gap between these bones may be normal in extreme ulnar deviation. Finally, the lunate will not flex normally during radial deviation.

When moving the hand in RUD, a widening of the scaphotrapezium-trapezoid joint is sometimes observed – this can be an indication of a radial-sided palmar CIND. Similarly, on radial deviation, a widened triquetrum-hamate joint can be observed and might be an indication of an ulnar-sided palmar CIND (Garcia-Elias, 2008; Wolfe et al., 2012).

The sudden ‘clunk’ of the PCR from flexion into extension, suggests a combined CIND (Lichtman and Wroten, 2006).

If a nonsynchronous movement between the lunate and triquetrum can be provoked during radial deviation, then a lunotriquetral dissociation may be suspected (Böttcher et al., 2005). In this, the triquetrum will move more distally than the lunate during radial deviation (Video 3).

Increased range of motion and a hypermobile lunotriquetral (LT) joint can be found in hypermobile patients (Garcia-Elias et al., 1995, 2003).

Lateral view: neutral position

In this view, the proximal border of the field should be just proximal to the distal radio-ulnar joint and the distal border at the level of the proximal third of the metacarpals. The radius and ulna should be projected over one another. The lunate bone should be covered by the scaphoid and the distal pole of the scaphoid covered by the pisiform (Brink et al., 2010).

An increased SL angle (³ 60°) or increased radiolunate angle (≥ 12°) in which the lunate is in an extended position (DISI) may indicate a static SLD (Sulkers et al., 2014a).

In patients with a dorsally displaced distal radius fracture, the lunate can be rotated palmarly to compensate for the increased inclination of the distal radial joint surface. The capitate is then collinear with the lunate, but dorsal to the longitudinal axis of the radius. Alternatively, the increased inclination of the distal radial joint surface will be compensated by relative flexion of the capitate, whereby the capitate is collinear with the radius, but dorsal to the longitudinal axis of the radius (Figure 2).

These compensations suggest an adaptive CIND (Lichtman and Wroten, 2006).

Signs of a VISI, in which the lunate and scaphoid are in flexion and the posterior horn of the lunate may project onto the capitate, suggest a lunotriquetral dissociation (Linn et al., 1990; Ritt et al., 1998). However, a VISI pattern may also present in patients with radial-, ulnar-, or combined CIND.

Lateral view: flexion/extension (FE)

After examining the wrist in neutral position in the lateral view, the wrist must be moved actively from extension to flexion within the limits of pain. This is repeated in a passive manner by the examiner to possibly achieve an increased range of motion. This should be repeated until all movements of the carpal bones have been visualized and assessed.

In normal circumstances where the SL ligament is intact, the lunate moves from extension to flexion and passes the 0° line of the radiolunate angle without any problems (Video 4). However, if the lunate does not pass the 0° line of the radiolunate angle during flexion, there is a high probability of dynamic SL instability (Video 5 and Appendix 2). A lunate that stays in an extended position during flexion implies a static SLD.

Finally, if the capitate can flex or extend more than 90° then a hypermobile wrist is suspected.

Lateral view: RUD

After flexion/extension in the lateral view, the wrist should be moved actively from ulnar deviation to radial deviation under continuous fluoroscopy within the limits of pain. Subsequently, the examiner obtains passive RUD in order to achieve a possibly increased range of motion.

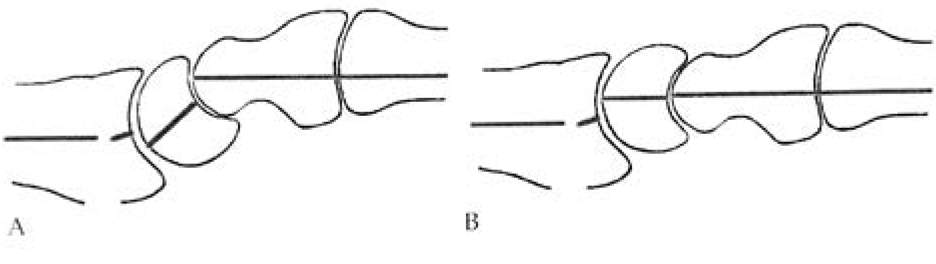

Figure 2. Adpative CIND. In patients with a dorsally displaced distal radius fracture, the increased inclination can be compensated by a relative flexion of the capitate. In this movement the capitate is collinear with the radius, but dorsal to the longitudinal axis of the radius (A). Alternatively, the lunate can be rotated palmarly to compensate for the increased inclination of the distal radial joint surface. The capitate is collinear with the lunate, but dorsal of the longitudinal axis of the radius (B).

In a normal wrist, the lunate will flex and extend during RUD (out-of-plane movement of the PCR) (Video 4). However, if the lunate does not flex fully and is in a more extended position during radial deviation, a dynamic SLD may be suspected (Video 6) (Linn et al., 1990; Ritt et al., 1998).

If the lunate stays in an extended position during radial deviation then a static SLD is present. If rotation of the PCR from flexion to extension is jerky this may indicate a radial- or ulnar-sided palmar CIND.

If the PCR is flexed during radial deviation, while during ulnar deviation, the PCR clunks into extension (as in a palmar CIND), a combined CIND is suspected. In addition, extreme ulnar deviation causes a dorsal subluxation of the capitate, similar to dorsal CIND.

If intact carpal ligaments are incapable of preventing excessive dorsal translation of the capitate and ulnar deviation produces a clunk on dorsal translation, a dorsal CIND is suspected (Lichtman and Wroten, 2006).

Provocation tests

The midcarpal shift test can be performed to diagnose a palmar CIND (Lichtman and Wroten, 2006). The patient's wrist is placed in a neutral position. Palmar translation is then applied so that the PCR is flexed. In this flexed position, the wrist must be simultaneously axially loaded and ulnarly deviated. By adding ulnar deviation the PCR is forced into extension. This motion may produce a rapid 'catchup clunk' in which the PCR jumps from flexion into extension (Lichtman and Wroten, 2006). The test result is positive for a palmar CIND if a painful clunk occurs and reproduces the patient's symptoms. If the clunk does not reproduce the patient's symptoms, the diagnosis of hypermobile or lax wrist can be made (Video 7). This test can be performed in both the PA and lateral views. In the PA view, the lunate and scaphoid will always move synchronously.

During the anterior drawer test the distal carpal row (DCR) is translated into a palmar direction. On the PA view, a widening of the scaphotrapezium–trapezoid joint can be seen in patients with a radial sided palmar CIND. In these patients, a palmar capitolunate subluxation can be seen on the lateral view (Video 8).

The dorsal capitate displacement stress test (Mayfield et al., 1980) or posterior drawer test are useful for diagnosing a dorsal CIND. The examiner applies dorsally directed pressure, while at the same time applying longitudinal traction to the wrist. In the lateral view cineradiography shows dorsal subluxation of the PCR and almost complete dorsal subluxation of the capitate from the lunate, in which the capitate may be brought beyond the dorsal lip of the lunate (Garcia-Elias, 2008; Lichtman and Wroten, 2006) (Video 8). The diagnosis of capitolunate instability pattern is made if instability at the capitolunate joint reproduces the patient's symptoms (Lichtman and Wroten, 2006).

DISCUSSION

This protocol describes how we have performed wrist cineradiography since our institute implemented it as a diagnostic tool for diagnosing carpal instabilities in 1987. The protocol is based on the sparse literature that has been published since Arkless et al. first described wrist cineradiography in 1966 (Arkless, 1966).

With its sensitivity of 85%–90% and specificity of 90%–97%, wrist cineradiography has been shown to be a good modality for diagnosing SLDs (Langner et al., 2015; Pliefke et al., 2008; Sulkers et al., 2014a). Additionally, using a score sheet (Appendix 2), a recent study showed excellent inter-observer correlations (κ = 0.84) and good to excellent intra-observer correlations (κ = 0.72–0.80) (Sulkers et al., 2014b).

Very few studies comparing cineradiography with the reference standard (arthrotomy or arthroscopy) for diagnosing lunotriquetral dissociation have been published (Böttcher et al., 2005). No sensitivity and specificity are calculated in these studies. Additionally, there is no gold standard for diagnosing a CIND or hypermobile wrist, as these are clinical diagnoses.

Cineradiography is the only available dynamic imaging technique that is able to detect a CID in real time, and therefore it is the only technique that can give information about the functional status of these joints. Carrying out stress tests (e.g. midcarpal shift test) under cineradiography can easily confirm the presence of a CIND, as the carpal kinematics typical of these tests are easily observed. Cineradiography is non-invasive, has relatively low costs, is widely available, and can be quickly performed.

A disadvantage of cineradiography is that patient and, to a lesser extent, the observer are both exposed to radiation with an average dose area product of 110 cGy X cm^2 (Pliefke et al., 2008), which is three times the dose of a chest X-ray (Dutch Institute of Public Health and Environment). Fluid movements are sometimes hard to observe as pulsed radiation is often used during cineradiography in order keep the dose area product as low as possible. Also at the acute stage, physical examination during cineradiography may be too painful and could induce false negatives. Finally, it takes time to learn how to obtain a good study and can therefore be operator dependent. However, this should be evaluated further, as no data on this topic are available in the literature.

Physical examination and conventional radiographs remain essential in the primary work-up for carpal instability. Positive findings suggest the presence of carpal instability. However, in the diagnosing of SLDs, due to the low sensitivity of the scaphoid shift test (Marx et al., 1999; Prosser et al., 2011) and of conventional radiographs (with or without static provocation tests, e.g. ulnar deviation views) (Sulkers et al., 2014a), we recommend cineradiography if there is clinical suspicion of CID.

Cineradiography is a qualitative rather than a quantitative tool, and more research is needed to determine its exact role in diagnosing carpal instability.

DECLARATION OF CONFLICTING INTERESTS

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

FUNDING

The authors received no financial support for the research, authorship, and/or publication of this article.

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CHAPTER 4

THE DIAGNOSTIC ACCURACY OF WRIST CINERADIOGRAPHY IN DIAGNOSING SCAPHOLUNATE DISSOCIATION

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The Journal of Hand Surgery, European Volume. 2013, 39: 263 – 271.

ABSTRACT

Ruptures of the scapholunate ligament (SLL) may cause carpal instability, also known as scapholunate dissociation (SLD). SLD may lead to osteoarthritis of the radiocarpal and midcarpal joints. The aim of this retrospective study was to determine the diagnostic value of wrist cineradiography in detecting SLD. All cineradiographic studies made during a 24 year period were retrieved. All patients who underwent the confirmation method (arthroscopy and/or arthrotomy) and cineradiography were included. In total, 84 patients met the inclusion criteria. Sensitivity, specificity, likelihood ratio, positive predictive value, negative predictive value, and diagnostic accuracy for detecting SLD were calculated for radiography and cineradiography. Cineradiography had a sensitivity of 90%, a specificity of 97%, and a diagnostic accuracy of 0.93 in detecting SLD. Radiography had a sensitivity of 81%, a specificity of 80%, and a diagnostic accuracy of 0.81. Cineradiography has a high diagnostic value for diagnosing SLDs. A positive cineradiography markedly increases the post-test probability of SLD.

INTRODUCTION

Ruptures of the scapholunate ligament (SLL) are common wrist ligament injuries (Gelberman et al., 2001). In association with distal radius fractures, the incidence of SLL tears found during surgery is approximately 36% (Geissler et al., 1996; Lindau et al., 1997; Richards et al., 1997). A tear of the SLL may cause a transarticular dissociation known as a scapholunate dissociation (SLD) (Garcia-Elias et al., 1995; Short et al., 2007; Watson and Ballet, 1984). SLD can be classified as *dynamic* SLD or *static* SLD (Chennagiri and Lindau, 2013; Cooney et al., 1990; Larsen et al., 1995; Short et al., 2007). Dynamic SLD causes a distortion of the scaphoid and lunate bones only during motion and return to their normal position at rest (Schmitt et al., 2006). This explains why dynamic SLD is frequently missed on conventional radiographs (Adolfsson and Povlsen, 2004; Hohendorff et al., 2012; Koh et al., 2012; Slutsky, 2008). Early recognition and consequently treatment of a dynamic SLD may prevent a static SLD, which in turn, may lead to degenerative attritional changes of the radiocarpal and eventually the midcarpal joint (O'Meeghan et al., 2003; Watson and Ballet, 1984). With a sensitivity of 69% and specificity of 64–68% (Marx et al., 1999), the scaphoid shift test (Watson et al., 1988) has been shown to be a poor test in detecting SLD. Therefore, additional imaging studies are needed for diagnosing or disclosing SLD. To diagnose dynamic SLD suggests the need for a dynamic radiodiagnostic technique. Wrist cineradiography is the only real-time radiological tool that can visualize bones in motion. This should be able to identify the absence or presence of synchronous movements between the scaphoid and lunate within their row. Therefore, cineradiography should be able to investigate the function of the SLL and, consequently, should be able to make a distinction between a dynamic and static SLD.

The aim of this retrospective study was to determine the diagnostic value of wrist cineradiography in detecting dynamic and static SLD.

METHODS

This retrospective study was performed at a tertiary care centre for hand and wrist surgery. Records of all consecutive wrist cineradiographies performed in patients with both acute and chronic complaints between July 1987 and May 2011 were reviewed. All patients with suspected carpal instability or wrist ligament injury received a wrist cineradiography during this period. Carpal surgery is considered the best confirmation method for diagnosing SLL injuries (Dohi et al., 2012). All patients who had wrist cineradiography followed by carpal surgery (wrist arthroscopy and/or arthrotomy) were included.

In these patients medical history, radiology reports of the cineradiographies, and reports from arthroscopy and/or arthrotomy were reviewed. We excluded cineradiographies of patients who had prior wrist surgery and patients familiar with skeletal and/or connective tissue disorders (e.g., rheumatoid arthritis). When patients met the inclusion criteria, we reviewed all conventional radiographies of the included patients. Outcomes of wrist cineradiography (primary objective) and conventional radiography (secondary objective) were compared with the confirmation method.

Wrist cineradiography

Wrist cineradiographies were performed by a radiologist following a strict protocol that was implemented ever since our institution started to use wrist cineradiography as a diagnostic tool. The borders of the field of view were defined proximally with the distal radius and ulna at the level proximal to the distal radioulnar joint (DRUJ) and distally with the first third of the metacarpal bones. Movements of the carpal bones were recorded on videotape, DVD, or digitally in picture archiving and communication system (PACS; Philips Medical Systems, Best, The Netherlands). To familiarize the patient with the examination and compare the injured to the non-injured wrist, the non-injured wrist was examined first. To reach a maximum range of motion, passive flexion/extension and radial/ulnar deviation were performed in both lateral and posteroanterior (PA) projections with continuous fluoroscopy. Additionally, we performed the midcarpal shift test in both directions. Cineradiography was considered positive if the movement of the scaphoid and lunate bones was not synchronous and/or a diastasis between the two bones could be provoked (Figure 1 and 2). On the lateral projections, cineradiography was positive when the lunate did not move synchronously with the scaphoid during flexion.

The results of the test were reported and stored in the patient record by the radiologist who performed the cineradiography. In this study, we relied on the radiology reports made by the radiologist.

Conventional radiography

Conventional radiographs were made in PA (Figure 3) and lateral views. All measurements were performed in a picture archiving and information system environment, where all radiographs are stored digitally.

Radiographs were considered positive for SLD when a minimum of one of the following was seen: a widened SL gap (≥ 3 mm) (Kuo and Wolfe, 2008), increased SL angle (≥ 60°) (Garcia-Elias et al., 1995; Megerle et al., 2011), or increased RL angle (≥ 12°). Additionally, the “cortical ring sign”, which is a sign of increased flexion of the scaphoid, was scored on the inspecting the frequency distributions (histograms). PA views (Gilula and Yin, 1996).

Surgery

All patients included in this study underwent wrist arthroscopy, arthrotomy, or both. When wrist arthroscopy showed an SLD in most cases an open repair or salvage was performed immediately.

During arthrotomy the SLL was scored as intact, lax, or partially or completely ruptured. An SLL was lax when the SLL was intact but there was a disproportional movement between the scaphoid and lunate bones. During arthroscopy SLL injuries were classified according to the Geissler classification (Geissler, 1995).

Figure 1. Wrist cineradiography PA series, dynamic SLD. Maximal radial abduction to maximal ulnar abduction. Note the clear widening in the middle image.

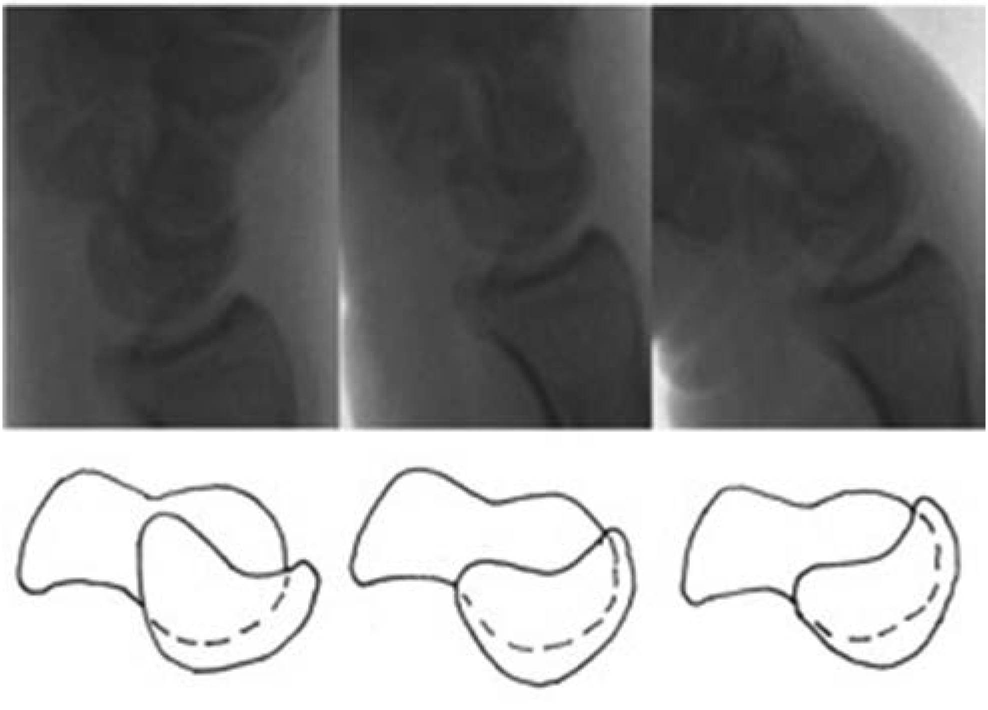

Figure 2. Wrist cineradiography lateral series. *Upper:* dynamic SLD series. Extension to flexion. *Below:* Movements of the scaphoid and lunate during static SLD (*left*), dynamic SLD (*middle*) and no SLD (*right*).

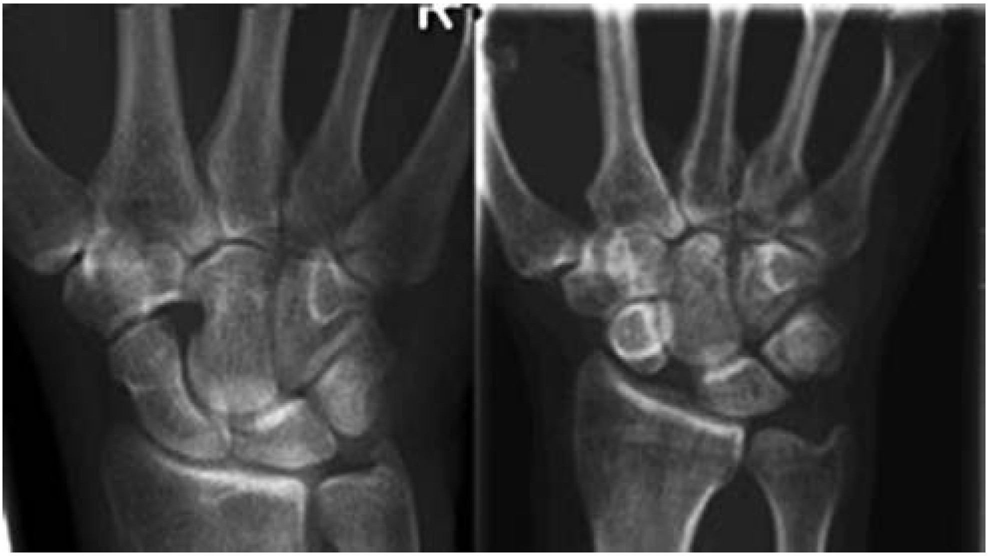

Figure 3. Conventional radiography, PA view. *Left:* suspected *dynamic* SLD. *Right:* suspected *static* SLD.

No differences between dynamic and static SLD could be made during arthroscopy or arthrotomy, because it was impossible to judge if the secondary stabilizers were intact or not.

To combine the results of arthrotomy and arthroscopy we made the following classification: a Geissler score of I on arthroscopy or an intact SLL during arthrotomy was classified as "no SLD". A Geissler score of II diagnosed with arthroscopy or a lax or partial ruptured SLL found during arthrotomy was classified as "stage-1-SLD". A Geissler score of III or IV or a ligament rupture found during arthrotomy was defined as "stage-2-SLD". When there was a discrepancy, we favoured the findings at arthrotomy over arthroscopy because of poor visibility in a few cases during arthroscopy.

Statistical analysis

Normality of continuous data was tested using the Shapiro–Wilk and Kolmogorov–Smirnov tests and inspecting the frequency distributions (histograms). Homogeneity of variances was tested using Levene's test.

Descriptive analysis was performed to assess baseline characteristics. For continuous data, mean (SEM) and standard deviation (SD) (parametric data) or medians and percentiles (non-parametric data) were calculated. For categorical data frequencies were calculated.

Differences in RL- and SL-angles and SL distances between patients with and without SLD were compared using the Student's t-test (parametric data) or Mann–Whitney U-test (non-parametric data). Differences were considered statistically significant when p values were < 0.05.

Sensitivity, specificity, likelihood ratio, positive predictive value, negative predictive value, and diagnostic accuracy for detecting SLD were calculated for conventional radiographs and wrist cineradiographies. For wrist cineradiography and static radiography 2 x 2 tables were made. A logistic regression analysis was performed to model the relationship between the covariates cineradiography, SL distance in millimetres on PA radiographs, and an SLD confirmed with arthroscopy or arthrotomy. To evaluate the goodness of fit of the logistic regression model, Nagelkerke's R-squared was calculated. Finally, a receiver operating curve (ROC) was calculated for the fitted model.

RESULTS

In almost 24 years, 1645 wrist cineradiographies were made in 829 patients. Only 85 wrists matched our inclusion criteria. In 62 of these wrists conventional radiographs were made. Of the 1560 excluded wrist cineradiographies, 91 cineradiographies were positive for SLD. Baseline characteristics are presented in Table 1.

Surgery

In total, 52 SLDs in 85 wrists (61%, 95% CI 50–71) were found during surgery. Median time between wrist cineradiography and the operation was 107 days.

Intra-operative findings are presented in Table 2. Of the 20 wrists that underwent both arthroscopy and arthrotomy, 12 wrists were diagnosed as a Geissler III/IV (stage-2-SLD) during arthroscopy; in one of these wrists the SLL showed only laxity (stage-1-SLD) during arthrotomy. In one wrist the SLL was not visible during arthroscopy; this wrist was diagnosed with a lax ligament during arthrotomy (stage-1-SLD).

Table 1. Baseline characteristics

N= 85 wrists	Mean (Range)
Age in years	39 (19 – 61)
Gender	*N* (%)
Men	47 (56)
Women	37 (44)
Side affected	**N = wrists (%)**
Right	54 (64)
Left	29 (35)
Both	1 (1)
Dominant side affected	**N = wrists (%)**
Yes	38 (45)
No	20 (24)
Unknown	27 (31)

Wrist cineradiography

A 2 x 2 table for wrist cineradiography is presented in Table 3. Four of the five false negatives were scored as stage-1-SLD and one was scored as stage-2-SLD during operation (Table 4). The false positive test was scored as a dynamic SLD during cineradiography.

Conventional radiography

Table 5 presents a 2 x 2 table for conventional radiography. Of the eight false-negative conventional radiographs, three were scored as stage-1-SLD and five were scored as stage-2-SLD during operation. Five of these false negatives were found to be positive during wrist cineradiography. All four false positives were scored suspected as dynamic SLD, as the SL distance in these wrists was < 3 mm, but a cortical ring sign or increased SL and RL angles were present.

Table 2. Findings during arthroscopy and/or arthrotomy

N = 85 wrists	Arthroscopy	Arthrotomy	Arthroscopy and Arthrotomy*	Total
No SLD	14	18	1	33
Stage-1-SLD	1	10	8	19
Stage-2-SLD	5	17	11	33
Total	20	45	20	85

*Results found during arthrotomy are presented.

Table 3. Cineradiography vs. the confirmation method

N = 85 wrists	SLD at confirmation method (+)	SLD at confirmation method (-)	Total
SLD at cineradiography (+)	47	1	48
SLD at cineradiography (-)	5	32	37
Total	52	33	85

Table 4. Cineradiography vs SLD stage on the confirmation method.

Cineradiography CM	No SLD	*Dynamic* SLD	***Static*** SLD	Total
No SLD	32	1	0	33
Stage-1-SLD	4	4	11	19
Stage-2-SLD	1	12	20	33
Total	37	17	31	85

CM= confirmation method; N= wrists

Carpal angles and cortical ring sign

Mean SL distances, and SL and RL angles between patients with and without an SLD were significantly different (Table 6). Every measurement apart, including the cortical ring sign, was compared with the confirmation method (Table 7).

Twenty-nine of 62 wrists had radiographs of both wrists. Differences in radiographic SL diastasis between the affected and unaffected wrists are shown in Table 8.

As presented in Table 7, an SL distance ≥ 3 mm had a specificity of 100%; this suggests a static SLD. Results of cineradiography and conventional radiography after excluding patients with an SL distance ≥ 3 mm are shown in Table 7.

Logistic regression analyses

Logistic regression analyses showed that a positive wrist cineradiography test combined with the absolute SL distance (mm) is a good predictor for diagnosing SLDs. The model for predicting the change of an SLD is: P (SLD) = 1/ 1 + $e^{-1(-7.88+7.18^{*}\text{ cineradiography}+\ 3.299^{*}\text{ radiography})}$.

The values for cineradiography are 1 when positive and 0 when negative, and the value of radiography is the SL gap measured in millimetres. The model showed that positive cineradiography (OR 1316; p = 0.01) and SL distance on radiography (OR 27 for each millimetre; p = 0.02) both independently predicted the presence of an SLD. We found a Nagelkerke R-squared of 0.88, meaning that approximately 88% of the variability can be explained by the model.

The corresponding area under the curve (AUC) for this model was 99% (95% CI 96–100), and is presented in Figure 4.

Table 5. Conventional radiography vs. the confirmation method

N = 62 wrists	SLD at confirmation method (+)	SLD at confirmation method (-)	Total
SLD at conventional radiography (+)	34	4	38
SLD at conventional radiography (-)	8	16	24
Total	42	20	62

Table 6. Findings on conventional radiographs, patients with vs. without SLD

	SLD Mean (SD)	No SLD Mean (SD)	r value
SL distance (mm)	3.21 (1.51)	1.25 (0.74)	< 0.001
SL angle (°)	63.52 (16.76)	47.88 (13.59)	0.001
RL angle (°)	8.83 (12.38)	1.03 (14.20)	0.031

Table 7. Test characteristics of conventional radiography and wrist cineradiography

	N	Sensitivity	Specificity	LR+	LR-	PPV	NPV	Accuracy
Cineradiography	85	0.90 (0.78 – 0.96)	0.97 (0.82 – 100)	29.83 (4.32 – 205.92)	0.10 (0.04 – 0.23)	0.98 (0.88 – 1.00)	0.86 (0.70 – 0.95)	0.93
Radiography	62	0.81 (0.65 – 0.91)	0.80 (0.56 – 0.93)	4.05 (1.66 – 9.84)	0.24 (0.12 – 0.46)	0.89 (0.74 – 0.97)	0.67 (0.45 – 0.84)	0.81
SL distance ≥3mm	62	0.52 (0.37 – 0.68)	1.00 (0.80 – 1.00)	∞ (NaN - ∞)	0.48 (0.35 – 0.65)	1.00 (0.82 – 1.00)	0.50 (0.34 – 0.66)	0.68
SL angle ≥ 60°	62	0.48 (0.32 – 0.63)	0.80 (0.56 – 0.93)	2.38 (0.94 – 6.05)	0.65 (0.48 – 0.90)	0.83 (0.62 – 0.95)	0.42 (0.27 – 0.59)	0.58
RL angle ≥ 12°	62	0.43 (0.28 – 0.59)	0.85 (0.61 – 0.96)	2.86 (0.95 – 8.58)	0.67 (0.51 – 0.89)	0.86 (0.63 – 0.96)	0.41 (0.27 – 0.58)	0.56
Cortical ring sign	62	0.52 (0.37 – 0.68)	0.75 (0.51 – 0.90)	2.10 (0.93 – 4.72)	0.63 (0.45 – 0.90)	0.81 (0.61 – 0.93)	0.43 (0.27 – 0.60)	0.60
After exclusion of patients with a SL distance of ≥ 3mm on conventional radiography								
Cineradiography	40	0.85 (0.61 – 0.96)	0.95 (0.73 – 1.00)	17.00 (2.49 – 115.86)	0.16 (0.06 – 0.45)	0.94 (0.71 – 1.00)	0.86 (0.64 – 0.96)	0.90
Radiography	40	0.60 (0.36 – 0.80)	0.80 (0.56 – 0.93)	3.00 (1.16 – 7.73)	0.50 (0.29 – 0.88)	0.75 (0.47 – 0.92)	0.67 (0.45 – 0.84)	0.70

Numbers between parentheses: 95% confidence interval.
SL distances, SL angles and RL angles were measured on conventional radiographs.
LR+ = positive likelihood ratio; LR- = negative likelihood ratio; N = wrists; NaN = not a number; NPV = negative predictive value; PPV = positive predictive value.

Table 8. Differences in SL distance in wrists with vs. without SLD on conventional radiographs.

	Mean, mm (SD)	r value
SLD N = 20		
SL distance affected wrists	3.13 (1.68)	0.001
SL distance unaffected wrists	1.56 (0.92)	
No SLD, N = 9		
SL distance affected wrists	1.03 (0.59)	0.147
SL distance unaffected wrists	1.09 (0.24)	

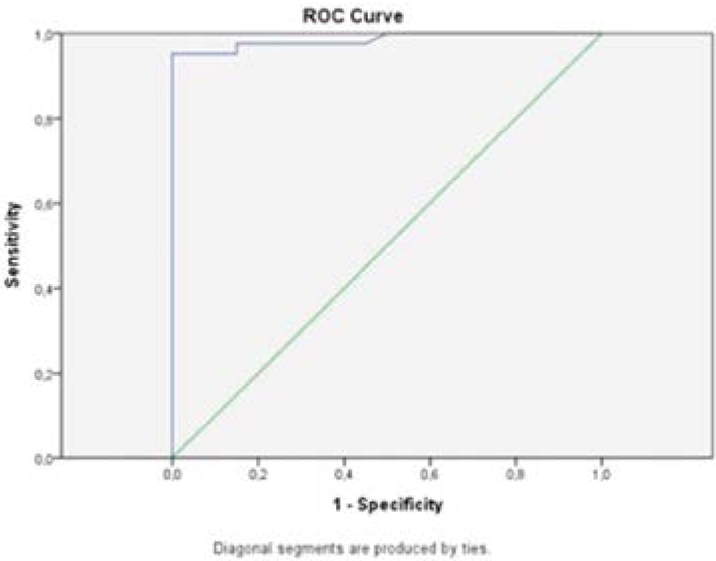

Figure 4. ROC for SL distance combined with cineradiography. The corresponding AUC for this model is 99% (95% CI 96-100).

DISCUSSION

This retrospective study shows a sensitivity of 90%, specificity of 97%, and diagnostic accuracy of 93% of wrist cineradiography in diagnosing a static and dynamic SLD combined. A positive cineradiography markedly increases the post-test probability of an SLD.

Radiography had a sensitivity of 81%, specificity of 80%, and diagnostic accuracy of 81%.

This difference in test characteristics between radiography and cineradiography may be due to the fact that cineradiography evaluates the movements of the scaphoid and lunate bones in real time, and therefore should also be able to diagnose dynamic SLDs. After excluding all radiographs with an SL distance ≥ 3 mm, 17 of 20 (85%) SLDs were found with cineradiography. The sensitivity of conventional radiography in this group decreases to 60%. Unfortunately, the secondary stabilizers could not be judged during the confirmation method. Therefore, no true difference could be made between diagnosing a static and dynamic SLD with radiography or cineradiography.

Several limitations of our study merit discussion. First, it was a retrospective series in which surgeons were not blinded to the findings of radiological imaging. Cineradiography was mostly performed after radiographs were taken, so the radiologists who performed cineradiography knew the results of radiography when they were present. This could mean that the diagnostic accuracy of cineradiography could be artificially high because the evaluation of the second test included knowledge about the first test. There was no independent verification of the cineradiology, and so the intra- and inter-observer reliability was not calculated. Only 85 of 1645 wrists met our inclusion criteria. This may be due to the fact that only patients suspected of SLD or with undefined complaints of the wrist were scheduled for surgery. Therefore, the prevalence of SLD (61%) in our study is higher than reported in the literature (31–54%) (Geissler et al., 1996; Laulan and Bismuth, 1999; Lindau et al., 1997; Pliefke et al., 2008). Of the excluded patients 91 had positive cineradiographies. This makes our results susceptible to partial verification bias. Not everyone in our group had a radiograph available for review; this can be explained by the fact that some patients brought their own radiographs from their referring hospital. These were eventually sent back and are therefore no longer available.

Since Arkless (1966) first described cineradiography, only a few studies have been published in which cineradiography has been studied for diagnosing SLDs. In these studies, sensitivity ranges between 43% to 86% and specificity between 64% to 95% (Braunstein et al., 1985; Pliefke et al., 2008).

Some centres recommend magnetic resonance imaging (MRI) for detecting SLDs. The sensitivity of MRI ranges between 41% and 86% and specificity between 46% and 94% (Anderson et al., 2008; Hobby et al., 2001; Haims et al., 2003; Moser et al., 2007; Prosser et al., 2011; Scheck et al., 1999). However, MRI only gives an anatomic evaluation of the SLL and limited information concerning the functional status of the SL joint. A perforation or partial tear in the SLL, although yielding leakage of dye into the neighbouring compartment, is not synonymous with a complete SLL disruption, and therefore MRI could make no distinction between dynamic and static SLD.

Cineradiography is the only dynamic imaging technique available that is able to detect SLD in real time, and therefore it is the only technique that can give information about the functional status of the SL joint. Cineradiography is non-invasive, has relatively low costs, and is widely available. Disadvantages of cineradiography are that it has a learning curve, might be operator dependent, and both patient and operator are exposed to radiation. In the acute stage, physical examination during cineradiography could be painful, which can induce false-negative results.

Conventional radiographs remain essential in the primary work-up for suspected SLD. Positive findings suggest the presence of an SLD. However, due to low sensitivity (60–80%), we recommend cineradiography when an SLD is clinically suspected. Our model has shown to be useful in discriminating which patients have an SLD with an AUC of 99%. However, preferably the model has to be validated in an external dataset.

Cineradiography appears to be a promising and helpful non-invasive diagnostic tool for diagnosing SLD. However, studies are needed to determine the estimated learning curve in making and evaluating cineradiographies. Additionally, inter- and intra-observer variability studies would be useful.

CONFLICT OF INTERESTS

None declared.

FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

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CHAPTER 5

SCAPHOLUNATE DISSOCIATION; DIAGNOSTICS MADE EASY

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European Journal of Radiology. 2017, 92: 45 – 50.

ABSTRACT

Scapholunate dissociation (SLD) is a form of carpal instability, caused by rupture of the scapholunate ligament (SLL) the secondary stabiliser of the scapholunate (SL) compartment. SLD can cause osteoarthritis of the wrist. Recently a study was published that shows cineradiography to be an excellent radiological imaging technique for diagnosing SLD at a tertiary centre for hand and wrist surgery (Sulkers et al., 2014a). As the quality of these results can be influenced by the expertise of the operator and observer of the cineradiographic studies, the aim of this study was to determine if these results were reproducible at a secondary centre for hand and wrist surgery with less expertise in wrist cineradiography. All cineradiographic studies carried out during a 10-year period were obtained. All patients who underwent the gold standard procedure (arthroscopy/arthrotomy) after cineradiography were included, a total of 50 patients. The diagnostic accuracy of detecting SLD by both cineradiography and conventional radiography was calculated. Cineradiography had a high diagnostic accuracy, while the accuracy for conventional radiography was average. When all wrists with an SL distance ≥3 mm were excluded (static SLD), diagnostic accuracy for conventional radiography dropped even lower, while accuracy for cineradiography remained high. These results are comparable with published accuracy rates and show that cineradiography has a high diagnostic value for detecting SLD and do not seem to be influenced by the operator or observer of the cineradiographic studies.

INTRODUCTION

Scapholunate ligament (SLL) tears are a common type of wrist ligament injury Mitsuyasu et al., 2004; Viegas et al., 1993; Viegas et al., 1999; Watson and Ballet, 1984). Tearing of this ligament can lead to abnormal alignment and kinematics of the wrist, also known as a scapholunate dissociation (SLD). SLD can be divided into dynamic and static SLD, classified by Watson et al. as follows: I partial tears without instability (predynamic); II a complete tear of the SLL without involvement of its secondary stabilisers (dynamic SLD) which causes distorted kinematics of the scaphoid and lunate bones only during motion, the lunate and scaphoid return to their normal position at rest; III complete tears of the

SLL including a tear of one or more secondary stabilisers of the SL joint (static SLD). Here, a malalignment between the scaphoid and lunate bones is found at rest.

A dynamic SLD can turn into a static SLD (Short et al., 2007; Watson and Ballet, 1984), and eventually into a scapholunate advanced collapse (SLAC) wrist (Mitsuyasu et al., 2004; Tanaka et al., 2008; Viegas et al., 1993; Watson et al., 1997; Watson and Ballet, 1984). These conditions all cause pain and loss of motion in the injured wrist.

By early recognition and treatment of a dynamic SLD these degenerative attritional changes may be avoided. However, dynamic SLD is frequently missed on conventional radiographs due to the fact that the scaphoid and lunate bones are able to return to their normal position at rest (Schimmerl-Mertz et al., 1999; Tanaka et al., 2008). It is only after a certain period of time that the carpal bones are no longer able to return to their normal configuration (static SLD). This means that degenerative attritional changes may already exist.

Over recent years, various clinical tests and radiological examinations to diagnose SLL tears have been described, with widely diverging diagnostic accuracy. Because of this, wrist arthroscopy or arthrotomy is still the gold standard of diagnosis. In 2014 Sulkers et al. carried out a study at a tertiary referral centre which showed cineradiography to have a high diagnostic accuracy with a sensitivity of 90% and a specificity of 97%. During wrist cineradiography, passive radial and ulnar deviation and flexion-extension of the wrist are examined under fluoroscopy for an average time of 72 s, using a tube voltage of 50 kV and a dose area product of 110 cGy cm^2 (Pliefke et al., 2008). A predictive model for diagnosing SLD was made by using both the outcome of the cineradiography and the value of the SL gap measured in mm on conventional radiography. The accuracy of this model was 99%. The aim of the present study was to determine if the diagnostic accuracy of cineradiography and the model published by Sulkers et al. in 2014 are reproducible at a secondary referral hospital with less expertise in obtaining cineradiographic studies of the wrist.

METHODS

This retrospective study was performed at a secondary care centre for hand surgery. All records of wrist cineradiographies within a ten-year period (2005-2015) were obtained and reviewed by the author. During this period the protocol was to acquire a wrist cineradiography when carpal instability or ligament injury was suspected. Arthroscopy or open exploration of the wrist is still the gold standard to diagnose SLL injury. Therefore, only patients who underwent cineradiographic studies followed by carpal surgery (wrist arthroscopy or arthrotomy) were included in this study. Patients who had prior wrist surgery were excluded. Patients with abnormal wrist anatomy, such as carpal fusions or Kienböck's disease were also excluded from this study. The medical histories, conventional radiographs, cineradiography reports and operative reports of all included patients were reviewed by the author. The outcomes of the cineradiography reports and conventional radiography images were compared with the gold standard, i.e., either wrist arthroscopy, wrist arthrotomy or both. All radiological and cineradiographic investigations were supervised by a board-qualified radiologist.

Conventional radiography

The radiographs of two patients were excluded because of their poor quality. In the other 48 patients, conventional radiographs were taken in standardised lateral and postero-anterior (PA) views. If available, the radiographs of both wrists were reviewed. All measurements were carried out using the Picture Archiving and Communication System (PACS, Philips Medical Systems, Best, The Netherlands) system, where all pictures were digitally stored.

Measurements taken from a conventional radiograph were considered positive for SLD if one of the following was seen: a widened SL gap ≥ 3.0 mm on PA view (Dornberger et al., 2015; Kitay and Wolfe, 2012), an increased SL angle ≥6 0° on lateral view (Chim and Moran, 2014; Megerle et al., 2011), or an increased RL angle of ≥ 12° on lateral view (Dornberger et al., 2015; Megerle et al., 2011). The distance between the scaphoid and lunate bone was measured in the midline of both carpal bones in accordance with the method of Schimmerl-Metz et al., 1999. The purpose of this measurement was to distinguish between static and dynamic SLD, as there might be a difference in the detection of static and dynamic SLD between conventional radiography and cineradiography. Additionally, the Gilula lines and the 'cortical ring sign' were also reviewed and scored on the PA views of all radiographs (Chim and Moran, 2014; Kitay and Wolfe, 2012; Megerle et al., 2011; Tanaka et al., 2008. All measurements were carried out by the author, a resident in plastic-, reconstructive- and handsurgery.

Cineradiography

Wrist cineradiography was performed on the radiology department by a radiologist or fellow in radiology, following a strict protocol. In this protocol both postero-anterior (PA) and lateral views were taken. The PA view is obtained with the patient's shoulder in 90° of abduction and the elbow in 90° of flexion. The wrist is then subjected to passive radial and ulnar deviation. If the movement between the scaphoid and lunate bone is not synchronous and a diastasis between the two bones is provoked, a dynamic SLD is suspected. This means the lunate moves partially with the scaphoid and the SL distance changes. Additionally, the lunate does not flex normally during radial deviation.

PA views were followed by the lateral views in which the patient's shoulder is held in a neutral position with the upper arm along the body, and the elbow held in 90° of flexion. The lateral wrist is then subjected to passive flexion/extension and radial/ulnar deviation. If the lunate does not pass the 0° line of the RL angle during flexion of the wrist, a dynamic SLD is suspected.

In this study cineradiography was considered positive if there was a suspicion of a (dynamic) SLD in either one of the views. The carpal bones in motion were recorded and stored digitally in PACS. In order to obtain maximum range of motion, passive flexion/extension and radial/ulnar deviation visualised in lateral and PA views. In all patients both wrists were investigated, starting with the non-injured wrist, to allow the patient to get accustomed to the procedure. Cineradiography was considered positive if the scaphoid and lunate bone did not move synchronously with each other in either of the views, or if a gap between the scaphoid and the lunate appeared during motion. In the lateral view, cineradiography was considered positive if the lunate did not cross the 0° line of the RL angle from extension to flexion.

The results were reported by the radiologist who carried out the test and the report was used for our study.

Operative treatment

As the gold standard for diagnosing SLL injury is surgery, patients were only included in this study if they had undergone arthroscopy, arthrotomy or both. This way we were able to compare radiological outcome with operative outcome. If wrist arthroscopy showed an SLD, open repair or a salvage procedure was carried out at the same time. During arthroscopy, the SLL was scored using the Geissler classification score (Geissler, 1995). At arthrotomy, the SLL was scored as either intact, lax, or as being partially or completely ruptured. To compare these scores, at arthroscopy we graded a Geissler stage 1 and an intact SLL during arthrotomy as 'no SLD'. In a similar way a Geissler 2 score and a lax or partially ruptured SLL were graded as a 'stage 1 SLD', and both a Geissler 3 or 4 and a ruptured SLL were graded as a 'stage 2 SLD'. All operative procedures were performed by a plastic surgeon with expertise in hand surgery.

Statistical analysis

Descriptive analysis of the data in this study was performed for baseline characteristics. Means (SEM) and standard deviations (SD) were calculated for continuous data, while frequencies were calculated for categorical data. Differences in RL- and SL- angles and SL distances with and without SLD were compared between wrists using a Student's t-test and were considered statistically significant if the P-value was < 0.05. The sensitivity, specificity, positive and negative likelihood ratio (LR), positive and negative predictive value (PPV/NPV) and diagnostic accuracy for detecting SLD of both conventional radiographs and wrist cineradiography studies were calculated.

A logistic regression analysis was performed on conventional radiographs to assess the predictive value of the variables cineradiography and SL gap on the outcome, SLD. The values for cineradiography were 1 when positive and 0 when negative, and the value of radiography was the SL gap measured in millimetres.

A Nagelkerke's R-squared calculated the goodness of fit of this model. In the article by Sulkers et al., 2014, a model was created for predicting the risk of an SLD, namely: P (SLD) =1/1 + e^ (−1(−7.88 + 7.18*cineradiography +3.299*radiography)). This model was tested for accuracy on the population of this study.

RESULTS

In this study 754 wrist cineradiography procedures were carried out in 377 patients. Both wrists were examined in all patients. Of the 754 wrist cineradiographs, 23 were excluded because there was no report on the cineradiography, there had been previous surgery on the injured wrist or the injured wrist had a genetic abnormality, such as Kienböck disease or carpal fusion, which would have made diagnostics in this study unreliable due to the different wrist kinematics. Of these 731 wrists in 366 patients, 681 wrist cineradiographs were not followed by carpal surgery, which left 50 wrists that met the inclusion criteria. See Table 1 for baseline characteristics.

Surgery

Twenty-three of the 50 patients included were diagnosed with SLD at operation (46%). In 29 cases, cineradiography was followed by wrist arthroscopy, 19 patients underwent arthrotomy and in two cases arthroscopy was followed by arthrotomy. Intra-operative findings are presented in Table 2.

Only two patients underwent both arthroscopy and arthrotomy. Both were staged as 'no SLD' at arthroscopy, but were converted to an arthrotomy because there was another indication for an open procedure. During arthrotomy both were again staged as 'no SLD'.

Conventional radiography

A two-by-two table for wrist cineradiography is presented in Table 4. The false negative was scored as a 'stage-1 SLD' at operation (see Table 5). The three false positives were scored as dynamic SLDs during cineradiography.

Carpal angles and cortical ring sign

Table 6 shows that the mean SL distances and SL and RL angles between patients with and patients without SLD were significantly different. The SL distance, SL and RL angle and the cortical ring sign were all separately compared to the confirmation method,

Table 1. Baseline characteristics.

Characteristics, N=50	Mean (range or percent)
Age, years	49,7 (16-83)
Gender	**N (%)**
Male	29 (58)
Female	21 (42)
Injured side	**N (%)**
Right	27 (54)
Left	23 (46)
Operation	**N (%)**
Arthroscopy	29 (58)
Arthrotomy	19 (38)
Both	2 (4)

Table 2. Findings during operative method.

N=50	Arthroscopy	Arthrotomy	Both	Total
No SLD	21	4	2	27
Stage 1 SLD	5	6	0	11
Stage 2 SLD	3	9	0	12
Total	29	19	2	50

Table 3. Conventional radiography versus operative method.

N = 50	SLD at operative method +	SLD at operative method -	total
SLD at CR +	17	7	24
SLD at CR –	5	19	24
NA	1	1	2
Total	23	27	50

CR =conventional radiography.
NA = non-assessable because of poor quality.

Table 4. Cineradiography versus operative method.

N=50	SLD at operative method +	SLD at operative method -	total
SLD at cineradiography +	22	3	25
SLD at cineradiography –	1	24	25
total	23	27	50

as shown in Table 7. This table shows that an SL gap ≥ 3 mm has a specificity of 97%, comparable to the specificity of conventional radiography of 96%. An SL gap ≥ 3 mm on conventional radiography suggests a static SLD.

After excluding all patients with an SL gap ≥ 3 (static SLDs), diagnostic measurements were repeated for conventional radiography and cineradiography, also shown in Table 7. The sensitivity of conventional radiography dropped from 77% to 62, while sensitivity of cineradiography only dropped from 96% to 92%.

Table 5. Cineradiography versus SLD stage during operative method.

OM\CR	No SLD	Dynamic SLD	Static SLD	total
No SLD	24	3	0	27
Stage 1 SLD	1	5	5	11
Stage 2 SLD	0	0	12	12
Total	25	8	17	50

OM = operative method.
CR = cineradiography.

Table 6. Findings on conventional radiographs, patients with versus without SLD.

N=50	SLD mean (SD)	No SLD Mean (SD)	P value
SL distance, mm	3,01 (1,41)	1,59 (0,54)	<0,001
SL angle, °	63,25 (10,91)	52,59 (9,46)	0,001
RL angle, °	13,24 (9,56)	4,76 (10,39)	0,006

Table 7. Test characteristics of conventional radiography and wrist cineradiography

	N	Sensitivity	Specificity	LR+	LR-	PPV	NPV	Accuracy
Cineradiography	50	0.96	0.89	8.62	0.05	0.88	0.96	0.92
Radiography	48	0.77	0.73	2.9	0.31	0.71	0.79	0.75
SL distance ≥ 3mm	48	0.47	0.97	13.9	0.54	0.9	0.74	0.77
SL angle ≥ 60°	50	0.7	0.8	3.5	0.38	0.7	0.L8	0.76
RL angle ≥ 12°	50	0.5	0.87	3.76	0.58	0.71	0.72	0.72
Cortical ring sign	48	0.27	0.85	1.77	0.86	0.6	0.58	0.58
After exclusion of patients with a SL distance of ≥ 3mm on conventional radiography								
Cineradiography	38	0.92	0.92	11.5	0.09	0.86	0.96	0.92
Radiography	38	0.62	0.76	2.6	0.50	0.57	0.79	0.71

Below the break: test characteristics after exclusion of patients with an SL distance ≥3 mm on conventional radiography.

Thirty-one of 50 patients had radiographs of both wrists. Table 8 shows the difference in SL gap between the affected and the unaffected wrist.

Prediction model

All 48 wrists were entered into the model and a two-by-two table was created, using a cut-off value of P= 0.5. This showed a sensitivity of 88% and a specificity of 76%, with an area under the curve (AUC) of 80%, presented in Fig. 1.

A new prediction model was made for this study population by logistic regression analysis, using the same variables. This model is: P (SLD)=1/ 1+e^ (−1(−4750+4468*cineradiography+0.658*radiography)). For this model, a new two-by-two table was made with a cut-off value of P=0.5. The sensitivity of this model was 93%, the specificity was 76% and the AUC was 82% (Fig. 2).

DISCUSSION

This retrospective study showed a diagnostic accuracy for cineradiography of 92% in diagnosing static and dynamic SLDs combined. Conventional radiography had a diagnostic accuracy of 75%. This shows that a positive cineradiography test increases the probability of an SLD. Both results are very similar to those of Sulkers et al. in 2014, which show a diagnostic accuracy of 93% for diagnosing an SLD with cineradiography and a diagnostic accuracy of 81% for conventional radiography.

In recent literature, sensitivities in the range of 86%–95% and specificities of 80%–97% for the detection of all scapholunate ligament tears with cineradiography are reported (Kwon and Baek, 2008; Pliefke et al, 2008; Sulkers et al., 2014a). For conventional radiography, reported sensitivities are 57%–81% and specificities are 80%–98% (Megerle et al., 2011; Pliefke et al, 2008; Sulkers et al., 2014a). Both are very similar to our results.

The difference in diagnostic accuracy between cineradiography and conventional radiography is probably due to the fact that cineradiography views the wrist in real-time motion and is therefore able to detect not only static but also dynamic SLDs. When we

Table 8. Differences in SL gap in wrists with and without SLD on conventional radiographs.

N=30	Mean, mm (SD)	P value
SL gap affected wrist		
SLD (N=17)	2,9 (1,5)	0,001
No SLD (N=13)	1,4 (0,5)	
SL gap unaffected wrist		
SLD (N=17)	1,7 (0,8)	0,932
No SLD (N=13)	1,7 (2,2)	

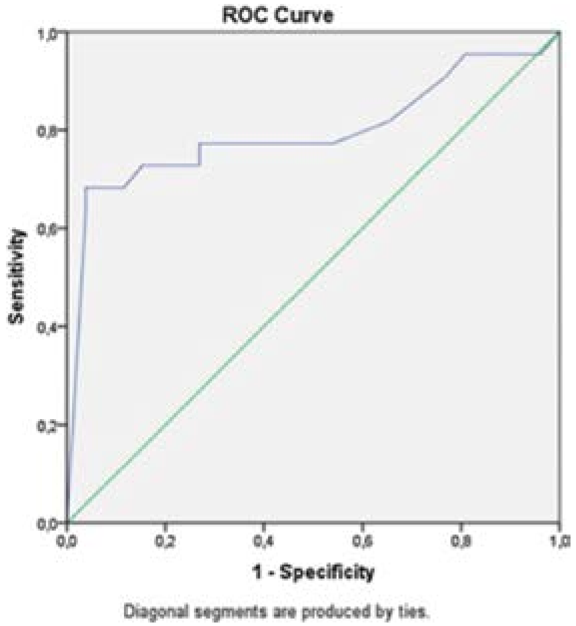

Figure 1. ROC curve for model P (SLD) =1/1 + e^ (–1(–7,88 +7,18*cineradiography + 3299*radiography)) with an AUC of 79,5%.

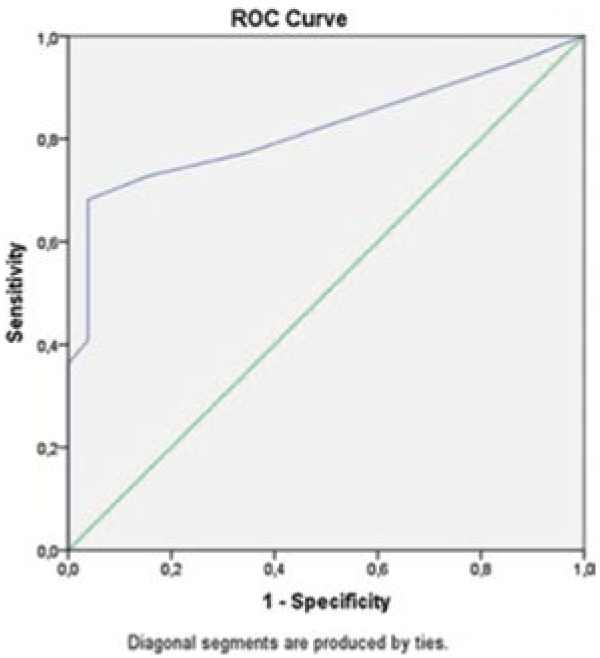

Figure 2. ROC curve for model P (SLD) =1/1 + e^ (–1(–4750 +4468*cineradiography + 0,658*radiography)) with an AUC of 82%.

exclude all patients with a SL gap of ≥ 3 mm (static SLDs), the sensitivity of conventional radiography drops to 62%, while cineradiography still has a sensitivity of 92%. This means that nine of the remaining ten patients with a dynamic SLD were positively identified by cineradiography. Unfortunately, the secondary stabilisers could not be evaluated by the confirmation method. Therefore, no real differentiation could be made between diagnosing a static or dynamic SLD with radiography and cineradiography.

Magnetic resonance imaging (MRI), computed tomography (CT), magnetic resonance arthrography (MRA) and computed tomography arthrography (CTA) are other commonly mentioned imaging techniques in diagnosing an SLD. MRA and CTA are generally considered superior to all other forms of computerised tomography or magnetic resonance imaging (1.5 T or 3 T) in diagnosing intrinsic ligament injury (Ramamurthy et al., 2016). Reported sensitivities range from 85%–100% for MRA (Braun et al., 2003; Lee RK et al., 2013; Lee YH et al., 2013; Pahwa et al., 2014; Scheck et al., 1999) and 80%-100% for CTA (Bille et al., 2007; De Felippo et al., 2010; Lee RK et al., 2013; Moser et al., 2007; Theumann et al., 2001; Schmitt et al., 2003). Specificities range from 80%–100% for both MRA and CTA (Ramamurthy et al., 2016). However, MRA and CTA are static imaging techniques that only give information about the anatomical situation of the SLL and do not give any dynamic information. Therefore, MRA and CTA cannot distinguish between static and dynamic SLD. In addition, in contrast to cineradiography, MRA and CTA are, both invasive techniques.

A new technique in this field is real-time MR imaging, which combines the advantages of cineradiography and MR imaging into one technique. Langner et al. reported a sensitivity of 85% and a specificity of 90% for detecting SLD with the cine-MRI in 2015, with a good interrater agreement and an excellent correlation to cineradiography. However, this technique currently requires a relatively long period of continuous wrist movement (35 s) and its clinical utility is limited by suboptimal spatial and temporal resolution limits (Boutin et al., 2013). Moreover, only small numbers of patients have participated in these studies. New studies should be carried out to confirm the diagnostic accuracy and determine the future role for this type of radiological imaging.

Another non-invasive technique is the carpal stretch test. In 1994 this test was first described and no additional value of this test was found (Fortems et al., 1994). Nevertheless other authors did find this test helpful in diagnosing SLDs (Schadel-Hopfner et al., 2005; Yamaguchi et al., 1998). Yet no sensitivity and specificity values were calculated in these studies. More recently an article was published in which manual traction was used for diagnosing SLD, in which a sensitivity and specificity of 78% and 72% was found respectively (Kwon et al., 2011).

There are some limitations to our study. First of all, only 50 of 731 patients were scheduled for surgery and therefore met our inclusion criteria. This was probably due to the fact that only patients suspected of having an SLD or with unexplained symptoms or severe pain were scheduled for surgery. This makes our study prone to both selection bias and verification bias. Still, the prevalence of SLD in this study (46%) was similar to reports in the literature (31%–54%) [(Geissler et al., 1996; Lindau et al., 1997; Pliefke et al., 2008).

As this was a retrospective study, the surgeons were not blinded to the findings of radiological imaging and the radiologists were not blinded to the findings of conventional radiographs, which were usually taken before cineradiography was done. This means that the diagnostic accuracy could be artificially high, because there was knowledge of the first test when performing the second test and there was knowledge of all test results when performing the gold standard test.

Currently cineradiography is still the only real-time dynamic imaging technique that can be widely used, is non-invasive and has relatively low cost. In addition, good inter- and intra-observer reliability has been reported for the technique (Sulkers et al., 2014b). Some disadvantages of the cineradiography are that both the patient and the operator are exposed to radiation, the investigation can be operator dependent and has a learning curve. If physical investigation is painful during cineradiography (which is usually only at the acute stage), it can influence the results.

Conventional radiographs remain very important in diagnosing SLDs, as they are very low-cost and easy to obtain. If the conventional radiograph suspicion for an SLD, further action is required. But if the conventional radiograph does not show SLD but suspicion of SLD remains, we would recommend performing cineradiography. This study confirms that cineradiography has high diagnostic accuracy in diagnosing SLD. However, further studies are needed to determine the learning curve in making and evaluating cineradiographs.

CONFLICT OF INTERESTS

None

FUNDING

The authors received no financial support for the research, authorship, and/or publication of this article.

ACKNOWLEDGEMENTS

No acknowledgements.

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CHAPTER 6

INTRAOBSERVER AND INTEROBSERVER VARIABILITY IN DIAGNOSING SCAPHOLUNATE DISSOCIATION BY CINERADIOGRAPHY

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The Journal of Hand Surgery, American Volume. 2014, 39: 1050 – 1054.

ABSTRACT

Purpose

To evaluate the intraobserver and interobserver variability in diagnosing scapholunate dissociation (SLD) by wrist cineradiography.

Methods

A musculoskeletal radiologist, hand surgeon, and trauma surgeon assessed the records of 50 consecutive wrist cineradiographies performed in 25 patients. Fluoroscopy was performed on the unaffected and affected wrist and consisted of radiographer-controlled passive flexion-extension and passive radial-ulnar deviation in both posteroanterior and lateral projections. To determine the intraobserver variability, the 3 reviewers reassessed all wrist cineradiographies 6 months after their first assessment. The kappa coefficient for interobserver agreement was calculated using the jackknife method. The Cohen kappa was used to assess intraobserver variability.

Results

The interobserver variability for diagnosing SLD by cineradiography was excellent (k = 0.84). The intraobserver variability for the hand surgeon was excellent (k = 0.80), and was good for the radiologist (k = 0.72) and the trauma surgeon (k = 0.76).

Conclusions

Cineradiography is a promising and helpful, noninvasive tool for diagnosing SLD. It is widely available and has relatively low costs. Conventional radiographs remain essential in the primary workup for suspected SLD. However, we recommend cineradiography when an SLD is clinically suspected.

INTRODUCTION

One of the most common type of wrist ligament injury is a rupture of the scapholunate ligament (SLL) (Gelberman et al., 2001). Rupture of the SLL may result in a dissociative-type carpal instability that results in altered wrist mechanics (Garcia-Elias et al., 1995; Short et al., 2007; Watson and Ballet, 1984). Carpal instability can be graded as dynamic or static (Schmitt et al., 2006; Watson and Ballet, 1984).

Conventional radiographs are used to diagnose static SLD, because the scaphoid shift test may not accurately diagnose SLD (Marx et al., 1999; Valdes and LaStayo, 2013; Watson et al., 1988). However, radiography may miss a dynamic SLD (Adolfsson and Povlsen, 2004; Slutsky, 2008). Therefore, dynamic radiologic imaging studies may help diagnose SLD, either static or dynamic. Cineradiography is the only real-time technique that can visualize bones in motion. During wrist cineradiography, passive radial and ulnar deviation and flexion-extension of the wrist are examined under a fluoroscope at an average time of 72 seconds, using a tube voltage of 50 kV and a dose area product of 110 cGy · cm2 (Pliefke et al., 2008) (Videos 1 and 4). The examiner should be able to identify the absence or presence of synchronous movements between the scaphoid and lunate. As evaluated by cineradiography, dynamic SLD is an asynchronous motion between the scaphoid and lunate during wrist motion, and a static SLD is a widening of the SL gap at rest (Schmitt et al., 2006). Previous studies have shown cineradiography to be a promising tool for diagnosing SLD (Braunstein et al., 1985; Pliefke et al., 2008). We recently found a sensitivity of 90% and specificity of 97% for cineradiography in diagnosing SLD in a retrospective study (Sulkers et al., 2014).

The purposes of this study were to evaluate interobserver and intraobserver variability in diagnosing SLD by cineradiography and to determine whether there was a difference in diagnostic accuracy between static and dynamic instabilities.

MATERIALS AND METHODS

This retrospective study was performed at a tertiary care center for hand and wrist surgery and received approval from our institutional review board.

A total of 25 patients suspected to have carpal instability had been previously evaluated with bilateral wrist cineradiography. Medical history and cineradiography reports of all included patients were reviewed. We excluded patients who had prior wrist surgery or had skeletal and/or connective tissue disorders (eg, rheumatoid arthritis). Average age was 40 years (range, 20 - 60 y). Twelve patients were men (48%). Fourteen wrists examined were right (56%), 10 were left (40%), and 1 patient was bilateral. The dominant side was affected in 14 patients (56%) and unknown in 2 (8%).

Wrist cineradiography

A radiologist performed wrist cineradiography following a strict protocol that was implemented from the time our institution started using wrist cineradiography as a diagnostic tool. Following this protocol, the borders of the field of view were defined proximally as just proximal to the distal radioulnar joint and distally at the proximal third of the metacarpals. Movements of the carpals were digitally recorded and stored in a picture archiving and communication system (Philips Medical Systems, Best, The Netherlands).

To familiarize the patient with the examination and compare the injured wrist with the uninjured wrist, we always examined the uninjured wrist first. To reach a maximum range of motion, radiographer-controlled passive flexion-extension and radial-ulnar deviation were performed in both lateral and posteroanterior (PA) projections with continuous fluoroscopy.

Because no conventional radiographs were reviewed for this study, cineradiography was considered positive for static SLD when the lunate remained stationary while the scaphoid moved during passive radial and ulnar deviation in the PA views, and/or the lunate stayed stationary and in an extended position while the scaphoid flexed during wrist flexion in the lateral views. However, during extreme radial and ulnar deviation and extreme flexion-extension, the lunate sometimes moved in the lunate fossa because of the position of the wrist, not because the lunate moved with the scaphoid (Videos 9 and 10) (Sulkers et al., 2014).

Dynamic SLD was diagnosed when the movement of the scaphoid and lunate was not synchronous and a diastasis between the 2 bones could be provoked by passive radial and ulnar deviation (Fig. 1). On the lateral projections, cineradiography was positive for a dynamic SLD when the lunate had a delayed flexion compared with the scaphoid. (Fig. 2 and Videos 2 and 5) (Sulkers et al., 2014).

Interobserver variability

To determine the interobserver variability of wrist cineradiography, all wrist cineradiographies were assessed for the purposes of this study by 3 medical specialists:

Figure 1. Wrist cineradiography PA series, dynamic SLD. Maximal radial deviation to maximal ulnar deviation. Note the clear widening in the middle image.

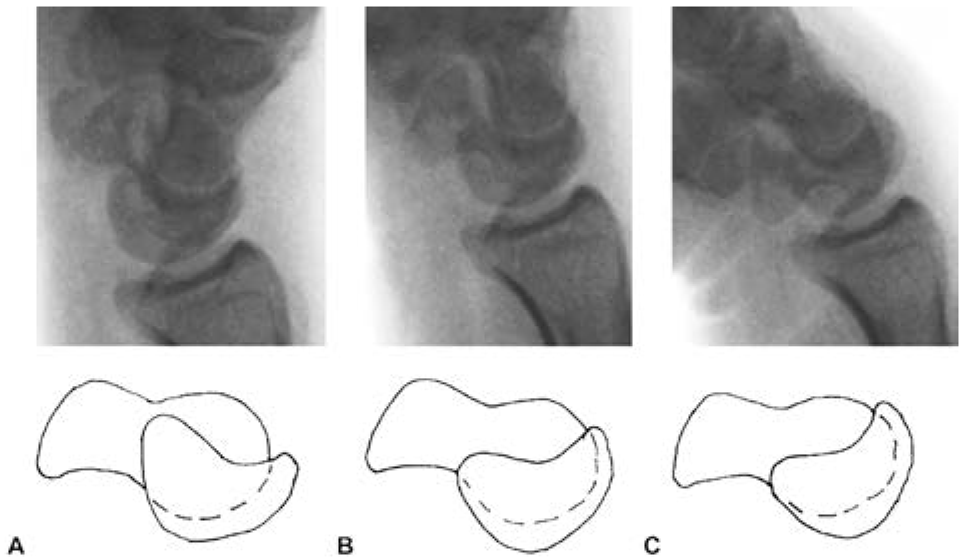

Figure 2. Wrist cineradiography lateral series. Upper: dynamic SLD series. Extension to flexion. Below: Movements of the scaphoid and lunate during static SLD (left), dynamic SLD (middle) and no SLD (right).

a musculoskeletal radiologist, a hand surgeon, and a trauma surgeon. Assessments were made on digital workstations. The musculoskeletal radiologist and the hand surgeon had experience of more than 20 years in analyzing wrist cineradiography. The hand surgeon was an expert in treating patients with SLD surgically for more than 20 years, whereas the trauma surgeon had 2 years' experience analyzing wrist cineradiography and 5 years' experience treating patients with SLD surgically. Assessments were made by an unvalidated score form (see Appendix 2). All specialists were blinded to the identity of the patient and to each other's scores. Cineradiography of the affected and unaffected wrists of each patient was shown so that the observers could compare the 2 wrists but scored them without knowledge of which wrist was affected. Patients were studied in random order.

To determine intraobserver variability, the 3 reviewers reassessed all wrist cineradiographs in the same manner 6 months after the first assessment.

Statistical analysis

We performed descriptive analysis to assess baseline characteristics. For continuous data, we calculated standard error of the mean and standard deviation (parametric data) or medians and percentiles (nonparametric data). Frequencies and percentages were calculated for categorical data.

The kappa coefficient for interobserver agreement among the 3 observers was calculated using the jackknife method. The basic form of the jackknife method works by estimating the coefficient with an iterative process. First, the coefficient is estimated from the whole sample; then, the coefficient is estimated, omitting each data value in turn. With this method, the bias of the estimation of the coefficient is reduced (Berger, 2007).

The Cohen kappa was used for intraobserver agreement with 1,000 bootstrap samples. Bootstrapping is a statistical method for estimating the sampling distribution of an estimator by sampling with replacement from the original sample (Cohen, 1960).

Based on its value, the kappa coefficient was summarized according to Landis and Koch as an excellent correlation (^{3} 0.8), a good correlation (0.6 - 0.79), a moderate correlation (0.4 - 0.59), or a poor correlation (< 0.4) (Landis and Koch, 1977).

RESULTS

Outcomes of the individual scoring forms are presented in Appendix 3.

There was an excellent correlation (k = 0.84) among the 3 specialists in diagnosing both static and dynamic SLD. When separating dynamic SLD from static SLD (Table 1), correlations between reviewers were k = 0.72 and 0.77, respectively.

In addition, the intraobserver agreement of all reviewers decreased when static SLD was separated from dynamic SLD (Table 2).

DISCUSSION

Intraobserver agreement for all 3 reviewers decreased when static and dynamic SLDs were separated. This could be because the reviewers had to make decisions regarding subtle

Table 1. Inter-observer variability in diagnosing a SLD, dynamic SLD and static SLD.

	First assessment	Second assessment	Overall κ
Dynamic and static SLD	0.72	0.84	0.84
Dynamic SLD	0.56	0.72	0.72
Static SLD	0.54	0.59	0.77

N = 50 wrists. All values are shown in kappa using the jackknife method.

Table 2. Intra-observer variability in diagnosing SLD using wrist cineradiography

	Radiologist	Hand surgeon	Trauma surgeon
Dynamic and static SLD	0.72	0.80	0.76
Dynamic SLD	0.67	0.44	0.56
Static SLD	X*	0.50	0.78

N = 50 wrists. All values are shown in Cohen's kappa and calculated were calculated with 1000 bootstrap samples per parameter.

*Intraobserver agreement of the radiologist could not be calculated for diagnosing a static SLD because he did not score 1 static SLD in the first assessment.

movements of the lunate during radial and ulnar deviation in the PA views, and flexion and extension in the lateral views. For example, during extreme flexion of the wrist, the lunate will flex owing to the position of the wrist and not because the lunate moves with the scaphoid. Also, when there was a clearly widened SL gap on the PA view in neutral position, sometimes the lunate was still moving with the scaphoid during extreme radial and ulnar deviation; again, this was caused by the position of the wrist. These movements of the lunate caused doubt for the reviewer in scoring between a static or dynamic SLD; yet, it was not possible to score a dynamic and static SLD in the same wrist. This may explain why the radiologist did not score 1 static SLD in the first assessment. It may also be the consequence of using an unvalidated scoring designed by our institute. However, during the second assessment, higher interobserver correlations were scored, which may have been because the observers were more familiar with the scoring form. Another limitation of our study was that we examined only 50 wrists.

Cineradiography is a promising and helpful, noninvasive tool to diagnose SLD. In a previous retrospective study with 85 wrists, we found a sensitivity of 90% and specificity of 97% using arthroscopy or arthrotomy as the reference standard (Sulkers et al., 2014). In other studies, the sensitivity ranged between 43% and 86%, and specificity between 64% and 95% (Braunstein et al., 1985; Pliefke et al., 2008).

Some investigators recommend magnetic resonance imaging (MRI) for diagnosing SLD. However, poor to moderate interobserver variabilities (k = 0.12 - 0.59)

are found using a 1.5-T MRI, with sensitivities and specificities varying from 41% to 86% and 46% to 90%, respectively (Anderson et al., 2008; Haims et al., 2003; Hobby et al., 2001; Manton et al, 2001; Moser et al., 2007; Prosser et al., 2011; Scheck et al., 1999).

Anderson et al. compared the sensitivity and specificity of 2 observers using 3.0-T MRI. However, no kappa was calculated in that study. Using 3.0-T MRI, sensitivities of 70% and 65% and specificities of 94% and 96% were described (Anderson et al., 2008; Lee et al., 2013).

Besides poor to moderate interobserver variability, MRI provides high variability in normal morphology. Also, MRI is more expensive in our institute (MRI of 1 wrist costs $444, compared with wrist cineradiography of both wrists at $184), and the patient examination takes more time (Lee et al., 2013; Pliefke et al., 2008). Therefore, an MRI study yields only anatomic evaluations of the wrist ligaments and gives limited information concerning their functional status. Thus, MRI cannot make a distinction between dynamic and static SLD. Conventional radiographs remain essential in the primary workup for suspected SLD. Positive findings (scapholunate distance of 3 mm or more, radiolunate angle of 12° or more, and/or scapholunate angle of 60° or more) suggest the presence of an SLD. However, because of low sensitivity (60% to 80%) (Sulkers et al., 2014), we recommend cineradiography when an SLD is clinically suspected. Cineradiography showed high sensitivity and specificity in diagnosing SLD in previous studies (Braunstein et al., 1985; Pliefke et al., 2008; Sulkers et al., 2014), and this study showed high interobserver and intraobserver agreement. Moreover, cineradiography is the only imaging technique available that is able to detect SLD in real time. Cineradiography is noninvasive, has a relatively low cost, is widely available, and can be quickly performed. Disadvantages of cineradiography are its learning curve, the risk of its being operator and observer dependent, and its radiation exposure. For acute injuries, physical examination during cineradiography may be so painful that the assessment is not feasible.

Our study indicates that when using a standardized scoring form, interobserver variability between reviewers was excellent, with good to excellent intraobserver variabilities in scoring dynamic and static SLD combined. However, our scoring form still has to be validated, and more studies with greater numbers of patients are needed to confirm our results.

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CHAPTER 7

LONG-TERM FUNCTIONAL RESULTS OF A WRIST EXERCISE PROGRAM FOR PATIENTS WITH PALMAR MIDCARPAL INSTABILITY

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Journal of Wrist Surgery. 2018, 7: 211 – 218.

ABSTRACT

Background

Patients with palmar midcarpal instability have symptoms of pain, combined with clinical signs of abnormal mobility on stressing the joint, an unpredictable blockade feeling, and a noticeable clunk, in the absence of an underlying trauma. No data are available on the effect of conservative treatment for these patients.

Purpose

The purpose of this study was to evaluate the effect and the long-term functional outcomes of a wrist exercise program in patients with palmar midcarpal instability.

Patients and Methods

All patients diagnosed with palmar midcarpal instability between 2005 and 2011 were included. Patients completed the Patient-Rated Wrist and Hand Evaluation (PRWHE) and the Short Form-36 health (SF-36) questionnaires, scaled their perceived pain before and after treatment, and indicated the effect of the received treatment.

Results

A total of 119 patients diagnosed with palmar midcarpal instability were included. The median follow-up time was 6 years (IQR 4.5–7.0). The median PRWHE score after hand therapy was 35.5 and the median mental component of the SF-36 score was 53.9 and the physical component was 45.2. The median perceived pain reduced from eight to four and the median therapeutic effect of the wrist exercise program was five.

Conclusion

Although palmar midcarpal instability remains to be a chronic disease, the effectiveness of our wrist exercise program is promising with acceptable long-term functional results and a good quality of life.

INTRODUCTION

Patients with palmar midcarpal instability have symptoms of pain, combined with clinical signs of abnormal mobility on stressing the joint, an unpredictable blockade feeling and a noticeable clunk, in the absence of an underlying trauma (Garcia-Elias, 2008). In palmar midcarpal instability, instability exists between the proximal carpal row and the distal carpal row, resulting in an abnormal movement pattern between the two (Harwood and Turner, 2016; Sivananthan et al., 2007; Wolfe et al., 2012). The abnormal movement pattern is a result of laxity of the ligaments that connect the distal radius, to both proximal and distal carpal row (e.g., dorsal radiocarpal ligament, the triquetrum-capitate-hamate (TqCH) ligament and scaphoid-trapezium-trapezoid [STT] ligament) (Larsen et al., 1995; Wolfe et al., 2012; Wright et al., 1994). Although a normal movement pattern of the wrist requires these ligaments to allow some laxity, in palmar midcarpal instability excessive laxity in the ligaments leads to abnormal motion between the proximal and distal row which is often associated with a painful clunk (Garcia-Elias, 2008; Hargreaves, 2016; Wolfe et al., 2012; Wright et al., 1994).

Although some surgical interventions have been proposed to augment or shorten the involved ligaments (Lichtman and Wroten, 2006; Ritt and de Groot, 2015; Sivananthan et al., 2007; Wright et al., 1994), a conservative strategy is most commonly advocated, as outcome of such surgery is often disappointing and unpredictable and therefore only recommended when conservative treatment fails.(Lichtman et al., 1993; Ming et al., 2014; Ritt and de Groot, 2015; Sivananthan et al., 2007). Conservative treatment strategies traditionally focus on immobilization with various wrist splints, isometric exercises, and reduction in pain with nonsteroidal anti-inflammatory medication (O'Brien, 2013; Prosser et al., 2007; Sivananthan et al., 2007; Wolfe et al., 2012; Wright et al., 1994). In 1999, our institution developed a wrist exercise program specifically for patients with chronic wrist pain, including carpal instability (Videler et al., 1999). This program aims to improve positioning, strengthening, and functional stabilization of the wrist during activities (Videler et al., 2016). The rational for using it for patients with palmar midcarpal instability is that this exercise program focuses on improving strength and coordination of the extrinsic muscle of the wrist and hand. Training these active stabilizers of the wrist may compensate for the ligamentous instability of the carpus and therefore improve qualitative control of movement and functional wrist stability (Esplugas et al., 2016). The exercises are as functional as possible and directed at the problematic actions of the patient. With the optimization of mobility and strength and the gradually increasing stability and complexity of movement, it is possible to work toward these problematic activities. Furthermore, the therapist helps the patient to become aware of wrist positioning, compensatory movements and pain provoking activities during daily activities and work.

The wrist exercise program was offered to all patients with palmar midcarpal instability presenting in our institution since 1999. Because our institution is a tertiary center for wrist pathology and patients are referred from all over the country, the program was designed to be provided by a local hand therapist. Consequently, patients do not routinely return to our center and therefore the long-term results of our wrist exercise program are still unclear. The aim of the current study was to determine the

effectiveness and long-term functional outcomes of a wrist exercise program in patients with the diagnosis palmar midcarpal instability at a minimum of 3 years of follow-up.

PATIENTS AND METHODS

Study design and Population

All patients that were diagnosed with palmar midcarpal instability in a tertiary center for wrist pathology between 2005 and 2011 were retrospectively included in this study. Palmar midcarpal instability was diagnosed by a surgeon specialized in hand surgery when the Lichtman test was found to be positive during both physical examination and during wrist cineradiography in the absence of any other wrist pathology (Lichtman and Wroten, 2006). The Lichtman test is defined as a palmar translation of the hand at the level of the distal capitate as the wrist is simultaneously loaded axially and moved from radial to ulnar deviation. The test is positive when a painful rapid "catch-up" clunk occurs as the proximal carpal row jumps from flexion into extension, reproducing the patient's symptoms (Lichtman et al., 1981; Ramamurthy et al., 2016; Toms et al., 2011). During wrist cineradiography, other carpal pathologies were excluded (e.g., carpal instability dissociative and/or a dorsal midcarpal instability) (Sulkers et al.,2018). Patients having palmar midcarpal instability combined with other wrist pathologies that were diagnosed either at clinical or radiological examination were excluded from this study.

Outcome

All eligible patients received an invitation to participate in the online survey. First they were sent a letter to join the online survey. Nonresponders were phoned and asked to participate. If they did not respond after three reminders, patients were considered lost to follow-up. The online survey was developed specifically for this study (Appendix 4).

Patient characteristics were acquired, and job history and ability to work were investigated. Occupation was divided into white collar (physically very demanding), blue collar (physically not demanding), homeworker, retired, and unemployed due to complaints of the wrist.

To specify the treatment and exercises received, patients had to indicate specific key exercises of the wrist exercise program. These specific key exercises were defined as exercises focused on a correct position of wrist and hand (e.g., "straight wrist" during lifting, supportive bandage, recommendations regarding position of the hand) (Fig. 1), and on stabilization of the wrist (e.g., "powerball," dynamic exercises with dumbbell, stabilization of a stock) (Fig. 2). Patients were considered to have followed the wrist exercise program if at least they had followed one of these two key exercises. As

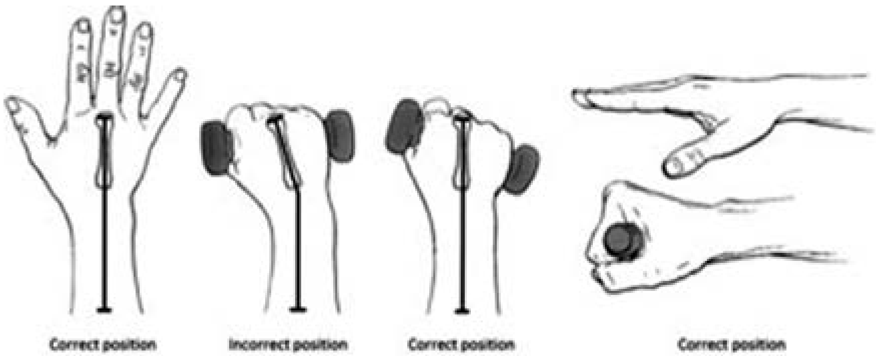

Figure 1. Correct position of the wrist

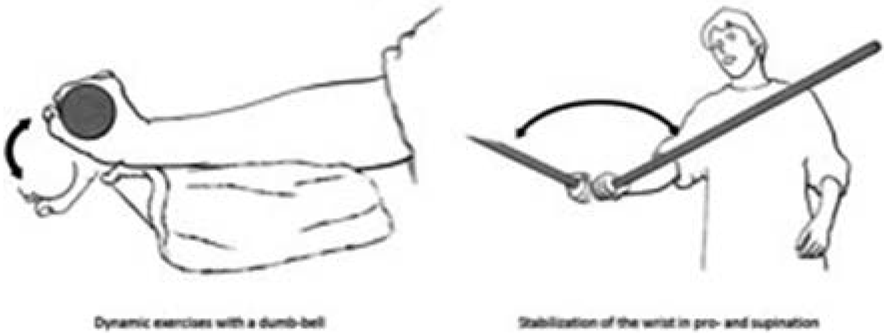

Figure 2. Stabilisation of the wrist

a control, questions on treatment aimed at sole improvement in mobility and flexibility, pain relief, massage, manipulation, and physio technical applications were added, as they are known interventions less specific for, or even contradictory to the principles of the exercise program. If patients followed these exercises in addition to at least one of the key exercises, they were included. However, if patients only followed these control exercises, they were excluded for this study.

Patients were asked if they still had complaints regarding the affected wrist, and in case they had, to scale their perceived pain before and after treatment using a numerical scale from 0 (no pain) to 10 (worst pain possible). Moreover, patients were asked to indicate the effect of the received treatment (therapeutic effect) at a numerical scale from zero (no effect) to ten (maximum effect). Furthermore, patients had to give an indication of the duration of their complaints before the treatment started and if they received additional treatment afterwards.

Finally, each participant completed the Dutch language version of the Patient-Rated Wrist and Hand Evaluation (PRWHE) and the Short Form-36 health (SF-36) questionnaires.

Both questionnaires are patient-reported outcomes. The PRWHE is a wrist-specific questionnaire on the basis of which patients have to rate their wrist pain and function on a scale of 0 to 10. The total score can be computed on a scale from 0 to 100. Higher scores indicate more pain and functional disability of the wrist (MacDermid, 1996; Macdermid et al., 1998). The SF-36 is a widely used health survey that contains 36 items divided into 8 subscales: physical and social functioning, limitations due to physical and emotional problems, physical pain, general health, vitality and mental health. Patients have to scale the positions with respect to their health in the past 4 weeks. The total score ranges from 0 to 100 with higher scores indicating a better state of health (Ware and Sherbourne, 1992).

Statistical analyses

Continuous data were presented as mean and standard deviation (SD) in case of normally distributed or as median and interquartile range (IQR) in case of non-normally distributed. Categorical data were presented as numbers with percentages. We used mean imputations to complete missing values of the questionnaires. The missing values in the PRWHE score were replaced per patient with the mean score of the concerning subscale if less than three questions were missing on the pain subscale and less than four questions on the function subscale as proposed by John et al., 2008. The missing values of the SF-36 were replaced with the mean of the total score per patient. Mean imputations for the SF-36 questionnaire were only used if less than 50% of questions per patient were missing, according to the SF-36 manual. The SF-36 is divided in a physical component score (PCS) and a mental component score (MCS). Both component scores are calculated with regression weights of the Dutch norm population. Data were analyzed using SPSS, version 23.0 (IBM, Armonk, New York, NY).

RESULTS

Included patients

We retrospectively identified 399 patients who underwent wrist cineradiography between 2005 and 2011. Due to a negative Lichtman test or co-existing wrist pathology, 96 patients were excluded. A total of 166 patients (55%) completed the questionnaire. Forty-seven patients were excluded because they did not follow the wrist exercise program, based on the specific key exercises. This left a cohort of 119 patients (Fig. 3).

The mean age of the patients at the time of wrist cineradiography was 29 years (SD 10.8) with a range of 11 to 64 years, and 84% were female. In 69% of the patients the dominant hand was affected, and 43 patients (36%) had bilateral palmar midcarpal instability. The median follow-up time was 6 years (IQR 4.5–7.0).

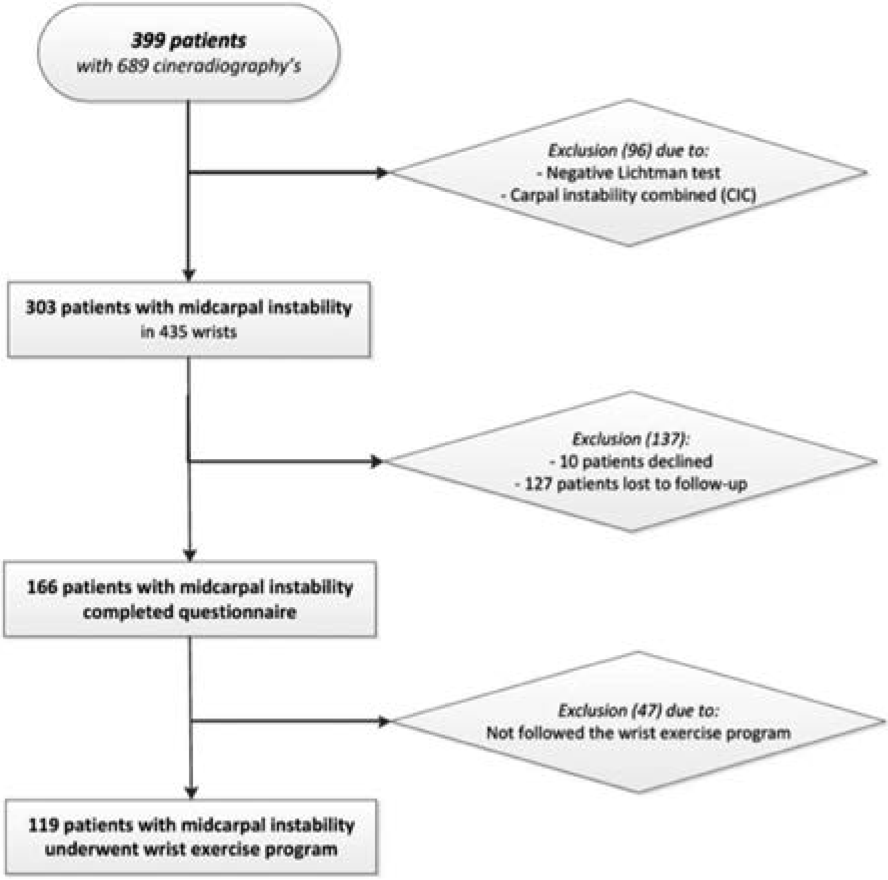

Figure 3. Flow diagram of patient selection

Effect of the wrist exercise program

At first presentation, 62% of the patients already had complaints of pain and dysfunction for more than 1 year. After the wrist exercise program, 19% of the patients did not have any complaints anymore. Of the remaining 81% of patients, the median perceived pain reduced from eight (IQR 7–9) before start of the wrist exercise program to four (IQR 2–6) at the time of follow-up. Moreover, the median therapeutic effect of the wrist exercise program was five (IQR 2–8).

The median PRWHE score was 35.5 (IQR 13.0–50.5). The MCS of the SF-36 was 53.9 (IQR 48.0–57.4) and the PCS was 45.2 (IQR 37.4–52.6).

The majority of the patients (60%) had a white-collar job (e.g., administrative work) (Fig. 4). In 40% of the patients, the wrist exercise program had a positive influence on the performance of the occupation. Thirty-one patients (27%) needed less adjustments and 15 patients (13%) could return to their previous occupational activities due to the wrist exercise program.

Compliance with the wrist exercise program

Of the 119 patients who followed the wrist exercise program, 91% of the patients were still following the wrist exercise program after 1 month and 61% of the patients completed the wrist exercise program with a minimum duration of 12 weeks. Besides a correct position (87.4%) and stabilization exercises of the wrist (76.5%), exercises aiming to improve strength (84%) were most often applied. Exercises aiming at coordination (29.4%), mobility and flexibility (29.4%), pain relief and perception (12.6%), massage and manipulation (15.1%), and physio technical applications (5.9%) were less frequent applied (Fig. 5).

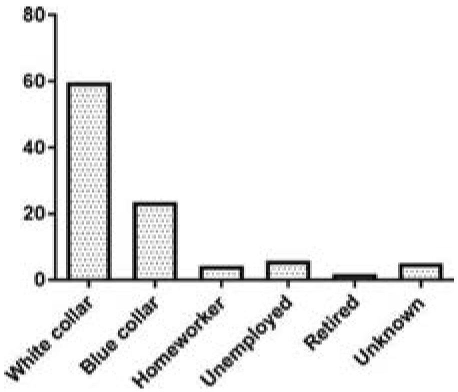

Figure 4. Occupations

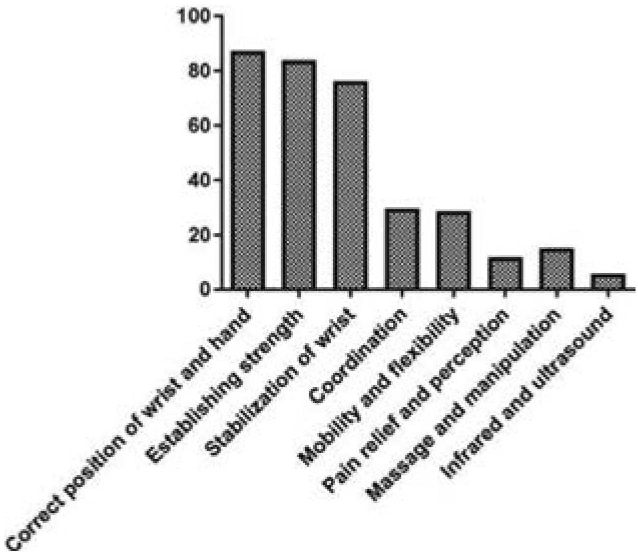

Figure 5. Wrist exercises

Additional treatment after the wrist exercise program

After the wrist exercise program, 42 patients (35%) received additional treatment; 21 patients had an operation, mostly due to a ganglion, 11 patients received a brace, splint or other supportive bandage, six patients went to a physiotherapist not specialized in this wrist exercise program, three patients went to an alternative doctor, and one patient received medication due to the diagnosis rheumatoid arthritis at later stage. The patient who was diagnosed with rheumatoid arthritis had still a pain score of eight at the time of completing in the questionnaire.

Nine patients (8%) had suffered from a new trauma of the wrist after the wrist exercise program, in particular a fracture of the wrist due to a fall on outstretched hand.

DISCUSSION

Palmar midcarpal instability is difficult to treat and often affects a relatively healthy and young population (Ritt and de Groot, 2015; Wright et al., 1994). The present study is the first to show satisfactory long-term results of a wrist exercise program for 119 patients with palmar midcarpal instability with a median follow-up of six years.

After the wrist exercise program, 19% of the patients reported no further wrist pain. Of all patients who still had complaints of the affected wrist, the pain reduced four points on a numerical scale. The median therapeutic effect of the exercise program was five (on a scale of 0 – 10). Although patients indicated that they benefit from the wrist exercise program, they still had a median PRWHE score of 35.5 after 6 years. However, the quality of life in our patient population is comparable to normative data for the Dutch population for females between 26 and 35 (mean of 48.5 for the MCS and 53.8 for the PCS). In a survey conducted in 2007 among 85 Australian Hand

Therapy Association members, the most often used treatments for patients with wrist instability were splints, isometric exercises of the wrist musculature, and education (Prosser et al., 2007). However, splints often only reduce pain in the short-term and the risks of splint-dependency exist. In contrast, by functional re-education and strengthening exercises, the wrist exercise program aims to improve positioning, strengthening, and functional stabilization of the wrist during activities not only in the short term but also in the long term.

In a previous study by Lichtman et al, evaluation of conservative treatment in palmar midcarpal instability, including splint, steroid injection, anti-inflammatory drugs, and avoidance of aggravating activities, resulted in a noted relieve of symptoms in 6 of the 10 patients. In four patients, conservative management failed and surgical stabilization of the triquetrohamate joint was required (Lichtman et al., 1981). In another study by Wright et al. in 1994, seven non-operatively treated patients were compared with 38 operatively treated patients. The non-operatively treated patients received a combination of splints, nonsteroidal anti-inflammatory medication and occasionally steroid injections, but the results were disappointing for both groups and only 60% of the non-operatively and operatively treated patients achieved good functional results. In both studies, the number of patients treated conservatively was low and no details regarding the therapy program were given.

Patients were included based on a positive Lichtman test during both physical examination and wrist cineradiography. Although wrist cineradiography is a globally accepted test to diagnose patients with palmar midcarpal instability, this test is not validated because there is no golden standard for diagnosing patients with palmar midcarpal instability (Toms et al., 2011). Besides, during physical examination we found that patients with palmar midcarpal instability also have a positive ulnar support test and tenderness during pressure at the triquetrohamate joint. Perhaps, these tests could be of additional value in diagnosing palmar midcarpal instability.

Limitations of the present study reflect the retrospective nature of the study. At follow-up, patients had indicate the amount of pain they had before treatment started, which may have been subject to recall bias. They also had to indicate how many and which exercises they received. Responses may have been influenced by the time to follow up or patients could have forgotten details of the exercises received. In addition, we did not have PRWHE scores from before start of treatment and, therefore we cannot show the effectivity of the program using this score. Furthermore, we chose to include as large a group as possible, as to our opinion, children with midcarpal instability in principle do not differ from adults. Our cohort included 18 subjects that were not adult at the time of follow-up. Although the PRWHE questionnaire has not been validated for children and adolescents, we chose not to exclude the patients based on age, as the PRWHE score did not change after excluding all minors from our analysis (median PRWHE score 36 [IQR 13.5–50.5]).

Lastly, selection bias may have occurred because we included only patients with a long history of complaints seen in a tertiary center for wrist pathology and we do not know what the natural course would have been. Therefore, we do not know if patients would have improved the same without the exercise program. The placebo effect is always a concern in uncontrolled studies, especially in the evaluation of intensive therapy regimes. A goal for future research would be including pretreatment PRWHE scores into a prospective study for patients with palmar midcarpal instability, and add a control group of patients not following the exercise program.

CONCLUSION

This is the first study evaluating the effectiveness of a wrist exercise program for patients with palmar midcarpal instability. We can conclude that the effectiveness of our wrist exercise program in patients with palmar midcarpal instability is promising for a wrist problem that is difficult to treat. Palmar midcarpal instability remains to be a chronic disease, reflected by the PRWHE score and the percentage of patients still having complaints after a median of 6 years. However, with the wrist exercise program, we can reduce pain, achieve acceptable longterm functional results, and a good quality of life.

CONFLICT OF INTEREST

None.

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CHAPTER 8

GENERAL DISCUSSION AND FUTURE PERSPECTIVES

GENERAL DISCUSSION AND FUTURE PERSPECTIVES

With this thesis we examined the usefulness of wrist cineradiography for diagnosing carpal instabilities. Readers must have noticed that mainly the diagnosis of a scapholunate dissociation (SLD) is examined. This is because of the fact that the results of cineradiography for carpal instability dissociative (CID) types only, can be compared with the reference standard (arthroscopy or arthrotomy). Within the CID type, a SLD is the most common form (concerning ligament injuries solely). Subsequently, only SLDs were included to examine the diagnostic accuracy of wrist cineradiography.

Although wrist cineradiography has been used for many years, there is limiting data concerning the validity for diagnosing carpal ligament injuries. This thesis showed that wrist cineradiography is a helpful tool for many of carpal ligamentous pathology especially diagnosing SLD. With cineradiography early stage (dynamic) SLDs can be diagnosed easily. And as described in **chapter 1**, this may be of substantial influence on treatment strategy. As treatment for a dynamic SLD is less invasive and more likely to be successful then for a static SLD or a scapholunate advance collaps (SLAC) (Chennagiri and Lindau, 2013; Chim and Moran, 2014).

In **chapter 2** we described the different forms of carpal instability non dissociative (CIND). Numerous theories about carpal instability are based on cadaveric studies or assumed theories of different authors. There is no conclusive evidence of the exact pathomechanics of the different forms of CIND. No evidence exists of which ligaments are exactly attenuated or lax. It seems that patients with hypermobile wrists are prone for developing a CIND, but it is not known why one patient with a hypermobile wrist develops symptoms and others don't, unless there's a clear history of a trauma of the wrist. In vivo evidence on this subject is hard to collect as there's no reference standard available for diagnosing CIND. However, mechanisms of CIND as described in **chapter 2**, are generally accepted, based on best available evidence. With this knowledge we presented in **chapter 3** the first structured protocol ever for obtaining and analyzing the different forms of carpal instability using cineradiography.

Diagnostic accuracy of wrist cineradiography

In **chapter 4** and **5** we showed a sensitivity up to 96% and specificity up to 97% for diagnosing SLD using cineradiography. Our results are similar to recent literature showing observed sensitivities of 85 % and specificities of 90 – 95% (Langner et al., 2015; Pliefke et al.,2008).

Conventional radiographs showed lower sensitivities and specificities. The differences found between cineradiography and conventional radiographs may be due to the fact that cineradiography evaluates the motion of the carpal bones in real time, and therefore cineradiography should be able to diagnose not only static SLD but also dynamic SLD. This is shown when patients with a static SLD, who had a SL distance of ≥ 3mm on the postero-anterior view on conventional radiographs, were excluded in our studies. The sensitivity of radiography decreased to 60%, while the sensitivity of wrist cineradiography remained around 90%. However, it must be noted that it is impossible to judge all secondary stabilizers of the SL joint during surgery and that therefore no true difference between dynamic and static SLD could be made.

Both studies had limitations. Both were retrospective studies in which the surgeons were not blinded to the findings of the radiological images. Wrist cineradiography was performed after the radiographs were taken, so the radiologist who performed cineradiography had knowledge of the results of the radiographs. This may cause an artificial high accuracy of wrist cineradiography because the evaluation of the second test was performed with knowledge of the first test. In addition, there was knowledge of all tests when performing the gold standard test. However, in the clinical setting the surgeon and radiologist have knowledge of all tests as well.

In both studies we made prediction models in which results of radiography and cineradiography were combined. The prediction model we made in 2014 showed a high prediction score (area under the curve of 99%) for diagnosing SLD (**chapter 4**). However, this prediction model was not applicable in the second study, which we performed in a center with less experience in obtaining wrist cineradiographies (**chapter 5**). So, no conclusions could be made using these models. Although, it should be questioned if a prediction model is necessary with the reported sensitivities and specificities for diagnosing SLD using wrist cineradiography (Langner et al., 2015; Pliefke et al., 2008).

Inter- and intra-observer variability of wrist cineradiography

In **chapter 6** we showed that wrist cineradiography has excellent inter-observer correlations (κ = 0.84) and good to excellent intra-observer correlations (κ = 0.72-0.80). Unvalidated score forms were used for this study which could have caused artificial high inter-observer and intra-observer correlations. Another limitation of this study was that there were only 50 wrists examined by three observers. However, the inter-observer variations we found, are comparable with the literature (Langner et al., 2015).

Protocol for diagnosing carpal instability using wrist cineradiography

Based on the results presented in **chapter 4, 5** and **6**, the experience we have developed in obtaining wrist cineradiographies since 1987, the available literature concerning wrist cineradiography and literature about the pathologic motions of the carpus in patients with carpal instability, we developed the first protocol for diagnosing carpal instabilities using wrist cineradiography (**chapter 3**). With this protocol we created uniformity in obtaining and assessing wrist cineradiography for diagnosing carpal instabilities. However, further research is necessary to validate the protocol. We must keep in mind that wrist cineradiography is well described for diagnosing SLD. But for diagnosing lunotriquetral dissociation only one study has compared cineradiography with the reference standard (Böttcher et al., 2005). Additionally, there is no reference standard for diagnosing the different forms of CIND as these are still clinical diagnoses. However, stress tests under cineradiography confirms the presence of a CIND, as the carpal kinematics typical of these tests are easily observed.

Our standardized protocol makes it easier for beginning radiologists to obtain and analyze a wrist cineradiograph. It is a misunderstanding that a lot of experience is necessary in obtaining and analyzing a wrist cineradiograph. Most experience is needed for performing a good Lichtman test while wearing radiation protection gloves. If this is a threshold for performing wrist cineradiography it is advisable to start with normal wrist movement (flexion/extension and radial/ulnar deviation in the lateral and PA plane) under fluoroscopy for diagnosing CID. It is a missed opportunity for an institution not using wrist cineradiography when a fluoroscope is available and there's a suspicion of a SLD. Because this may prevent a wrist arthroscopy or arthrotomy for a patient, which are invasive procedures.

Most important for analyzing wrist cineradiography, especially for beginners, is a good collaboration between the hand surgeon and radiologist as the hand surgeon has to give detailed clinical information to the radiologist to perform a good wrist cineradiography.

Other imaging modalities for diagnosing carpal instability

Some centers recommend magnetic resonance imaging (MRI) for diagnosing SLD. Sensitivities and specificities are up to 81% and 90% using a 1.5T MRI and 81% and 100% using a 3T MRI (Anderson et al., 2008; Haims et al., 2003; Lee et al., 2013; Moser et al., 2007; Prosser et al., 2011; Schädel-Höpfner et al., 2001; Scheck et al., 1999; Spaans et al., 2013). Other centers suggest magnetic resonance arthrography (MRA) or computed tomography arthrography (CTA). MRA showed sensitivities up to 97% and specificities up to 100%, while sensitivities and specificities up to 100% are found using CTA for diagnosing SLD (Bille et al., 2007; Braun et al., 2003; De Filippo et al., 2010; Lee et al., 2013; Moser et al., 2007; Scheck et al., 1999; Schmitt et al., 2003; Theumann et al., 2001). However, MRI, MRA and CTA are static imaging techniques that only give information about the anatomical situation and less about the functional status of the joint. Thus, MRI, MRA nor CTA could make a distinction between dynamic and static SLD. Moreover, MRA and CTA are invasive techniques. The most common side effect of MRA and/or CTA is pain (up to 1 week) due to injection of contrast fluid into the wrist. Other reported minor side effects are (chemical) synovitis, headache, tiredness, vasovagal reactions, increased blood sugar levels, pruritus and urticaria (De Filippo et al., 2010; Saupe et al. 2009). An uncommon but severe side effect of arthrography is a septic arthritis (Hugo et al., 1998).

A new technique in the field of diagnosing carpal instabilities is the use of cine MRI. Cine MRI combines the advantages of cineradiography and MRI. Langner et al., 2015 used cine MRI for diagnosing SLD showing a comparable sensitivity (85%) and specificity (90%) as wrist cineradiography. Additionally, an excellent inter-rater agreement was found

($\kappa = 0.81$), which is comparable with cineradiography as well. Finally, the acquisition time of cine MRI is comparable with wrist cineradiography.

Advantages of cine MRI are that there's no radiation exposure to patient and examiner and that MRI can visualize the ligamentous structures besides the carpal bones.

A possible disadvantage of cine MRI compared to cineradiography is that cine MRI is performed in a positioning device which moves the wrist in a passive manner. This may cause that not a full range of motion could be examined. Additionally, only the injured wrist is examined, which may be a disadvantage when slight differences are found in hypermobile patients where imaging of both wrists is desirable. Also, it is impossible to obtain stress tests using cine MRI. Therefore, the diagnosis of CIND using cine MRI is questionable. Finally, cine MRI might be more expensive as in our institute a static MRI of one wrist costs €405, in where wrist cineradiography of both wrists costs €168.

Another new technique for diagnosing carpal instability may be the 4 dimensional computed tomography (4D-CT). Arab et al., 2018 used 4D-CT for diagnosing SLD. Patients moved their injured wrist actively from radial to ulnar deviation for a several times and finally squeezed in a syringe to obtain a clenched fist view. A maximum sensitivity and specificity of respectively 86 and 91% was found for the images in which the patients moved their wrist from radial to ulnar deviation, which is comparable with sensitivities and specificities of cineradiography and cine MRI. A maximum sensitivity of 79% and specificity of 87% for the clench fist view images were found, which are lower compared to cineradiography. It must be noticed that 4D-CT images were not compared with the reference standard but with CTA, so no true sensitivities and specificities of 4D-CT may be given in this study. As in cine MRI and cineradiography, 4D-CT showed to have an excellent inter-rater agreement ($\kappa = 0.85$). Similar results were founded by Athlani et al., 2020 using the 4D-CT. However, small groups were evaluated and outcomes of 4D-CT were compared with CTA again.

Advantages of 4D-CT are that 4D-CT should be able to visualize the motion of the carpal bones with more precision and with a higher image quality compared to cineradiography. Additionally, 4D-CT has the opportunity to quantify carpal kinematics and may evaluate joint space thickness, which is a tool to quantify cartilage thickness. Also, the examiner is not exposed to radiation.

Comparable with cine MRI, disadvantages of 4D-CT are that only the injured wrist is examined and that it is impossible to obtain stress tests in order to diagnose CIND. Additionally, the patient is exposed to more radiation compared to cineradiography (227,9 mGy × cm vs 110 cGy × cm2) (Arab et al., 2018; Pliefke et al., 2008). And because of the complexity of 4D-CT, experienced laboratory personnel, including an engineer to edit the images, are needed to obtain and analyze a 4D-CT. A 4D-CT is not widely available yet, however most institutions do have a CT scanner. Nowadays, most CT scanners have the option of 4D rendering, which is a tool that can visualize the surface of the carpal bones during motion. Using this option, information can be given of carpal bone movements and great interruptions may be noticed. However, secure intercarpal motion analyses using 4D rendering is impossible.

Although cine MRI and 4D-CT are dynamic imaging techniques, cineradiography remains the only available dynamic imaging technique that can give real time information about the functional status of the joint and its ligaments. This may be beneficial when a surgeon suspects a carpal instability during an operation in where no cine MRI or 4D-CT is available. Besides the low costs, almost all centers do have a fluoroscope and therefore cineradiography is in the clinical setting more applicable for the upcoming years.

A disadvantage of cineradiography is that patient and observer are both exposed to radiation. However, in our institute we measured effective doses between 1 – 3 mSv, which is 0.03% of the effective dose of an X-ray of the chest. Also, the more experience a radiologist has, the lower the dose area product will be. Because with more experience in obtaining wrist cineradiography it is acceptable to think that a Lichtman test (e.g.) will be performed more effectively. Additionally, at the acute stage, wrist cineradiography may be too painful to perform which could induce false negatives.

Wrist exercise program

In **chapter 7** we presented a pilot study assessing the effectiveness of a wrist exercise program for the treatment of palmar CIND. In this study we used wrist cineradiography for diagnosing CIND, but especially to rule out other carpal instabilities. The program was initially set-up for patients with chronic complaints of the wrist and aimed to improve positioning, strengthening, and functional stabilization of the wrist during activities. Patients with palmar CIND were offered the exercise program since 1999, and the aim of this study was to evaluate the effectiveness and long-term functional outcome of this program for these patients.

The retrospective nature and the possible recall bias were limitations of this pilot study. However, we showed that the effectiveness of the exercise program in patients with palmar CIND is promising. Pain reduction and acceptable long-term functional results, with a good quality of life may be achieved. Palmar CIND showed to be a chronic disease, reflected by the percentage of patients still having complaints after 6 years. Conservative treatment remains the primary treatment for patients with palmar CIND. Although, no definitive conclusions can be made after this pilot study. More research in treating patients with a palmar CIND in a conservative manner is necessary.

Future perspectives

A lot is unknown about the exact motions of the carpal bones in the injured wrist and wrists suffering chronic pain. Lots of classifications of carpal instability and subsequently treatment strategies are based on theoretical thoughts and cadaveric studies. Knowledge about the exact pathology in these wrists is essential before any classification and treatment strategy can be made. Relatively more literature has been published the last few years concerning treatment strategy of carpal instability compared to literature focusing on pathology, kinematics and diagnosing carpal instability. It would be more logical to focus on these topics instead of focusing on treatment strategies.

4D imaging may play an important role for future research as it gives important information about the exact kinematic changes of the carpal bones in patients suffering carpal instability (Arab et al., 2018; Langner et al., 2015). With expected improvements of data acquisition time and imaging quality cine MRI may be an important tool for understanding and diagnosing all types of carpal instabilities. As not only bones but also ligaments are able to be visualized using cine MRI.

However, 4D-CT and cine MRI are not widely available yet. Therefore, cineradiography will play an important role for the upcoming years. It is desired that future research on cineradiography will follow a standardized protocol, like we presented in **chapter 3**, to obtain uniform data concerning carpal instability. Following this standardized protocol more radiologists could be trained in performing and analyzing cineradiographies. An e-learning module may be helpful but should be made and subsequently validated first. This should make the use of cineradiography for diagnosing carpal instabilities more popular among radiologists and hand surgeons.

CONCLUSION

This thesis showed that wrist cineradiography is a promising tool, with a high sensitivity, specificity and an excellent inter-observer correlation for diagnosing carpal instability problems such as SLD and CIND. Wrist cineradiography plays an important role for diagnosing the different forms of CIND, as the carpal kinematics typical of these tests are easily observed. However, more research is needed concerning the pathomechanics and kinematics of CIND.

Physical examination and conventional radiographs remain essential in the primary work-up for carpal instability. Positive findings suggest the presence of carpal instability. However, in diagnosing SLDs, due to the low sensitivity (61 – 69%) and specificity (64 – 68%) of the scaphoid shift test (Marx et al., 1999; Prosser et al., 2011) and of conventional radiographs, we recommend cineradiography if there is clinical suspicion of ligamentous carpal instability.

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CHAPTER 9

SUMMARY

SUMMARY

The wrist is a complex joint, the stability of which is created by a balance between the bones of the wrist (carpal bones), the ligaments of the wrist and the tendons of the forearm.

Instability of the carpal bones may develop due to hyperlaxity of the ligaments of the wrist or to an injury to one or more of these ligaments. Some forms of carpal instability can lead to extensive and painful arthritis, and the subsequent deterioration of the function of the wrist.

Carpal instability can be divided into three groups: a dissociative form known as carpal instability dissociative (CID), a non-dissociative form known as carpal instability non-dissociative (CIND), and a combination of both carpal instability combined or complex (CIC).

CID is defined as a transarticular and/or transossal dissociation in the proximal or distal carpal row. The most well-known forms are a non-union of the scaphoid and a scapholunar dissociation (SLD). An SLD can be further divided into three stages: predynamic, dynamic and static.

As in dynamic and predynamic SLD the intercarpal relationships are not disrupted in the resting position, it is difficult to make an accurate diagnosis by means of a radiograph. However, this is not true of the more advanced stage of static SLD as here the intercarpal relationships are disrupted in the resting position.

It is important for the patient that an SLD should be diagnosed at the earliest stage possible in order to minimalize loss of function.

Wrist cineradiography is the only dynamic radiological investigation that is able to image the carpal bones in real time while the wrist is moved in several directions. This investigation provides good images of the carpal bones and enables the visualization of the movement between the scaphoid and the lunate bones (amongst others). In this way it is possible to diagnose both predynamic and dynamic SLD.

In this doctoral thesis we will focus on the diagnosing of an SLD by using the wrist cineradiography.

In **Chapter 2**, the various forms of a CIND are discussed. Additionally, the pathomechanics, clinical presentation, diagnostic work-up and treatment of the various forms of CIND are explored in depth.

Chapter 3 comprises a protocol that we developed for the diagnosis of the various forms of carpal instability. This protocol is based on the extensive experience of the Amsterdam UMC (location AMC) in making wrist cineradiographies, on the outcomes that are presented in **Chapters 4, 5** and **6** and on the current literature.

Chapter 4 contains a retrospective study that was carried out at a center with a great deal of expertise in making wrist cineradiographies. In this study, cineradiographies of patients with suspected SLD are examined and compared with the gold standard - arthrotomy and/or wrist arthroscopy. A sensitivity of 90% and a specificity of 97% for the diagnosing of an SLD were found for wrist cineradiography.

To check if similar results were to be found from the wrist cineradiograph at a center where there was less expertise in making videos of the wrist, the study was repeated at a different center. This study is presented in **Chapter 5** and shows that comparable results were found for diagnosing an SLD by means of wrist cineradiography; in this case a sensitivity of 96% and a specificity of 89%.

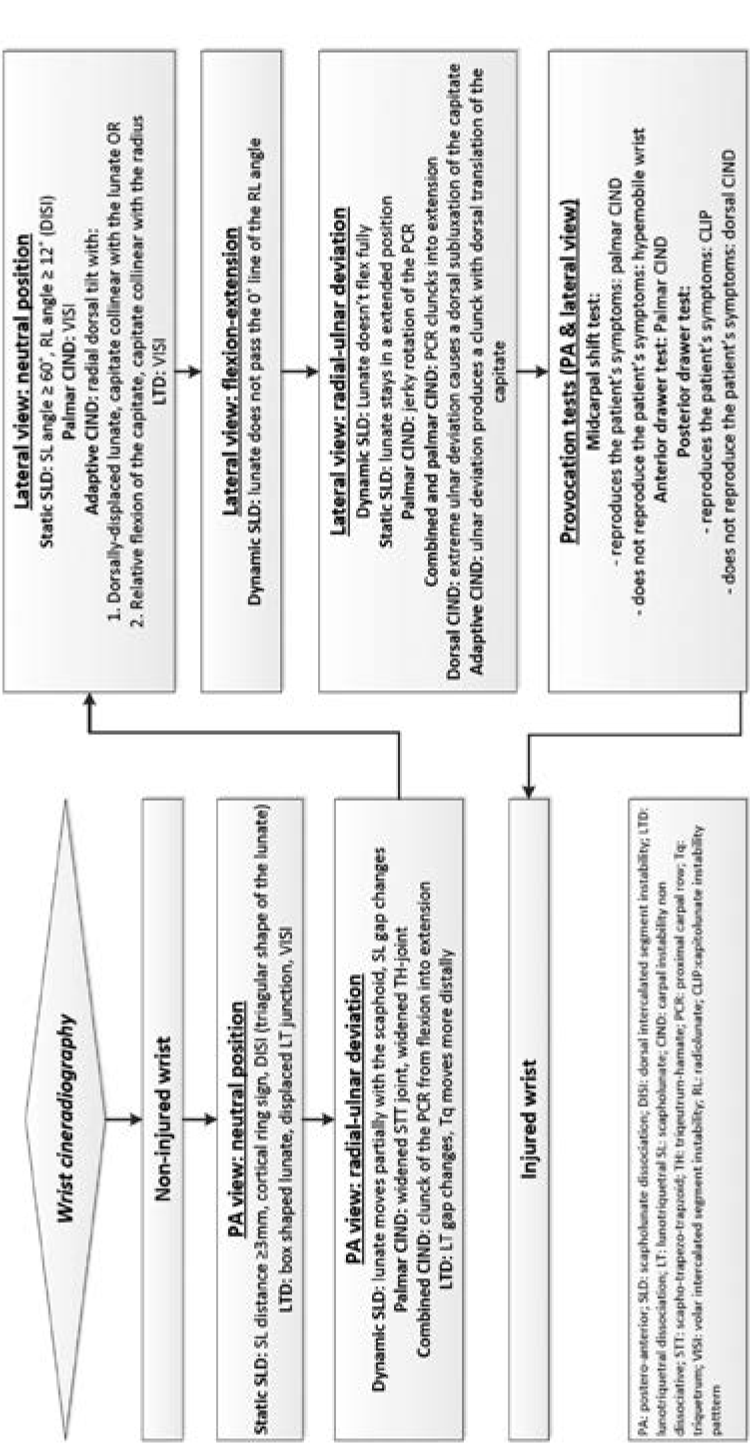
In **Chapter 6** we investigated what the inter-and intra-observer variability would be for diagnosing an SLD by means of a wrist cineradiography. This investigation was carried out with the cooperation of a radiologist, trauma surgeon and a hand surgeon. The inter-observer variability was excellent (k = 0.84) and the intra-observer variability was good to excellent (k = 0.72 – 0.80).

In **Chapter 7** we conducted a pilot study into the wrist exercise program for patients with palmar CIND (the most common form of CIND). The results showed very promising long-term outcomes for those patients who had followed the wrist training program.

The Discussion section of this doctoral thesis is presented in **Chapter 8.**

APPENDICES

APPENDIX 1


Wrist cineradiography
Non-injured wrist
PA view: neutral position
Static SLD: SL distance ≥3mm, cortical ring sign, DISI (triagular shape of the lunate)
LTD: box shaped lunate, displaced LT junction, VISI
PA view: radial-ulnar deviation
Dynamic SLD: lunate moves partially with the scaphoid, SL gap changes
Palmar CIND: widened STT joint, widened TH-joint
Combined CIND: clunck of the PCR from flexion into extension
LTD: LT gap changes, Tq moves more distally
Injured wrist
PA: postero-anterior; SLD: scapholunate dissociation; DISI: dorsal intercalated segment instability; LTD: lunotriquetral dissociation; LT: lunotriquetral SL: scapholunate; CIND: carpal instability non dissociative; STT: scapho-trapezo-trapzoid; TH: triqeutrum-hamate; PCR: proximal carpal row; Tq: triquetrum; VISI: volar intercalated segment instability; RL: radiolunate; CLIP:capitolunate instability patttern
Lateral view: neutral position
Static SLD: SL angle ≥ 60˚, RL angle ≥ 12˚ (DISI)
Palmar CIND: VISI
Adaptive CIND: radial dorsal tilt with:
1. Dorsally-displaced lunate, capitate collinear with the lunate OR
2. Relative flexion of the capitate, capitate collinear with the radius
LTD: VISI
Lateral view: flexion-extension
Dynamic SLD: lunate does not pass the 0˚ line of the RL angle
Lateral view: radial-ulnar deviation
Dynamic SLD: Lunate doesn't flex fully
Static SLD: lunate stays in a extended position
Palmar CIND: jerky rotation of the PCR
Combined and palmar CIND: PCR cluncks into extension
Dorsal CIND: extreme ulnar deviation causes a dorsal subluxation of the capitate
Adaptive CIND: ulnar deviation produces a clunck with dorsal translation of the capitate
Provocation tests (PA & lateral view)
Midcarpal shift test:
- reproduces the patient's symptoms: palmar CIND
- does not reproduce the patient's symptoms: hypemobile wrist
Anterior drawer test: Palmar CIND
Posterior drawer test:
- reproduces the patient's symptoms: CLIP
- does not reproduce the patient's symptoms: dorsal CIND

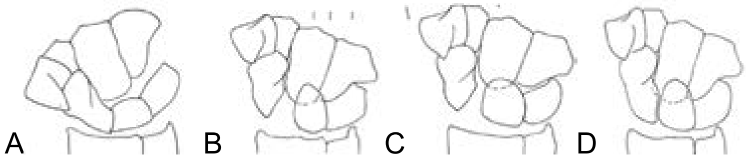
APPENDIX 2

Wrist cineradiography SLD scoring form

PA view: radial-ulnar deviation

Widening of the SL gap must be scored

0: Lunate stays stationary compared to the scaphoid, SL gap increases
1: Lunate moves partially with scaphoid, SL gap changes
2: Lunate moves synchronously with scaphoid, SL gap stays normal



PA view

A. Radial deviation. B. Ulnar deviation: lunate stays stationary compared to the scaphoid and the SL gap increases. *C. Ulnar deviation:* lunate moves partially with scaphoid and the SL gap changes. *D. Ulnar deviation:* lunate moves synchronously with scaphoid and the SL gap stays normal.

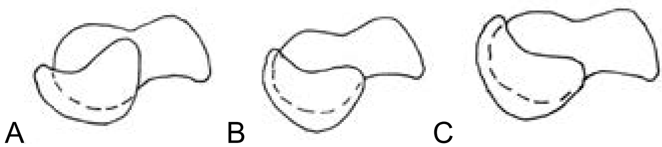
Note: During extreme radial and ulnar deviation or flexion/extension the lunate may move in the lunate fossa due to the position of the wrist. This is not because the lunate moves along with the scaphoid.

Lateral view: flexion-extension

Movement of the lunate compared to the scaphoid must be scored

0: Lunate doesn't move with the scaphoid and stays in an extended position
1: The lunate has a delayed flexion compared to the scaphoid
2: Lunate moves synchronously with the scaphoid

Note: During extreme flexion of the hand, the lunate will flex due to the position of the wrist. This is not because the lunate moves along with the scaphoid.



Lateral view

A. Scaphoid flexes and the lunate stays in an extended position. The lunate doesn't pass the 0° line of the RL angle. B. Scaphoid flexes and the lunate moves partially with the scaphoid. The lunate just passes the 0° line of the RL angle. C. The scaphoid flexes and the lunate moves synchronously with the scaphoid. The lunate passes the 0° line of the RL angle synchronously with the scaphoid.

Classification of a SLD

No SLD: Both, in PA view and lateral view,the observer scored a "2" (synchronous movements of the scaphoid and lunate)

Dynamic SLD: Minimum one "1" is scored in the PA and/or lateral view by the observer (asynchronous movements in PA and/or lateral view).

Static SLD: Minimum one "0" is scored in the PA or lateral view by the observer (The lunate remains stationary in the PA view and/or stays in an extended position on the lateral view).

APPENDIX 3

Scoring form outcomes

Patient	Side	Affected	R1	R2	PS1	PS2	TS1	TS2	ORR	SO
1	L	YES	DYN	DYN	DYN	DYN	NO	DYN	DYN	SLD*
	R	NO	DYN	DYN	STAT	DYN	DYN	DYN	NO	NA
2	L	NO	NO	NO	NO	NO	NO	NO	NO	NA
	R	YES	NO	NO	NO	NO	NO	NO	NO	NO
3	L	YES	NO	NO	NO	NO	NO	NO	NO	NO
	R	NO	NO	NO	NO	NO	NO	NO	NO	NA
4	L	NO	NO	NO	NO	DYN	NO	NO	NO	NA
	R	YES	NO	NO	NO	NO	NO	NO	NO	NO
5	L	YES	DYN	NO	NO	NO	NO	NO	NO	NO
	R	YES	NO	NO	NO	NO	NO	NO	NO	NA
6	L	NO	DYN	DYN	STAT	STAT	STAT	STAT	DYN	NA
	R	YES	DYN	DYN	STAT	STAT	STAT	STAT	DYN	SLD*
7	L	NO	NO	NO	DYN	DYN	NO	DYN	NO	NA
	R	YES	DYN	DYN	STAT	STAT	STAT	DYN	DYN	SLD*
8	L	NO	NO	NO	DYN	NO	NO	NO	NO	NA
	R	YES	DYN	DYN	STAT	STAT	STAT	STAT	DYN	SLD*
9	L	YES	NO	NO	NO	NO	NO	NO	NO	NO
	R	NO	NO	NO	NO	NO	NO	NO	NO	NA
10	L	YES	NO	NO	DYN	NO	DYN	DYN	NO	NO
	R	NO	NO	NO	NO	NO	NO	NO	NO	NA
11	L	NO	NO	DYN	STAT	DYN	DYN	DYN	NO	NA
	R	YES	DYN	DYN	DYN	DYN	DYN	DYN	NO	NO
12	L	YES	DYN	DYN	DYN	STAT	DYN	DYN	DYN	SLD*
	R	NO	DYN	DYN	DYN	DYN	DYN	YN	NO	NA
13	L	YES	DYN	STAT	STAT	STAT	STAT	STAT	DYN	SLD*
	R	NO	DYN	DYN	STAT	DYN	DYN	NO	NO	NA
14	L	YES	DYN	NO	NO	NO	NO	NO	NO	NO
	R	NO	NO	NO	NO	NO	NO	NO	NO	NA
15	L	NO	NO	NO	NO	NO	NO	NO	NO	NA
	R	YES	DYN	DYN	DYN	DYN	STAT	DYN	NO	NO
16	L	NO	DYN	NO	NO	NO	NO	NO	NO	NA
	R	YES	NO	NO	DYN	DYN	NO	NO	NO	NO
17	L	NO	NO	NO	NO	DYN	NO	NO	NO	NA
	R	YES	NO	NO	DYN	DYN	NO	NO	NO	NO
18	L	NO	NO	DYN	DYN	DYN	DYN	DYN	NO	NA
	R	YES	NO	NO	DYN	STAT	DYN	NO	NO	NO
19	L	YES	DYN	DYN	DYN	STAT	DYN	DYN	NO	NO
	R	NO	DYN	DYN	DYN	DYN	DYN	DYN	NO	NA
20	L	NO	NO	DYN	DYN	DYN	NO	DYN	NO	NA
	R	YES	DYN	DYN	DYN	STAT	DYN	DYN	DYN	SLD*

Appendix 3. (continued)

Patient	Side	Affected	R1	R2	PS1	PS2	TS1	TS2	ORR	SO
21	L	YES	NO	NO	NO	NO	NO	NO	NO	NO
	R	NO	NO	NO	NO	NO	NO	NO	NO	NA
22	L	NO	NO	NO	NO	NO	NO	NO	NO	NA
	R	YES	NO	NO	NO	NO	NO	NO	NO	NO
23	L	YES	DYN	DYN	DYN	DYN	DYN	DYN	DYN	SLD*
	R	NO	NO	NO	NO	NO	DYN	NO	NO	NA
24	L	NO	NO	NO	DYN	NO	NO	NO	NO	NA
	R	YES	NO	NO	NO	NO	NO	DYN	NO	NO
25	L	NO	NO	DYN	NO	DYN	NO	DYN	NO	NA
	R	YES	DYN	DYN	DYN	DYN	DYN	DYN	NO	SLD*

Side: L=Left, R=Right; R1: 1st scores of the radiologist, R2: scores of the radiologist after 6 months; PS1: 1st scores of the plastic surgeon, PS2: scores of the plastic surgeon after 6 months; TS1: 1st scores of the trauma surgeon, TS2: scores of the trauma surgeon after 6 months; ORR = original radiological report; SO = surgical outcome (arthroscopy or arthrotomy), *no difference between dynamic and static SLD could be made during surgery as the secondary stabilizers of the SL joint couldn't be judged during surgery.
NO = No SLD, DYN = dynamic SLD, STAT = static SLD, NA= not available

APPENDIX 4

Personal details

1. What is your dominant hand?

☐ Left
☐ Right
☐ Both

2. From which wrist, you have/used to have complaints? Please choose the wrist with the most complaints.

☐ Left
☐ Right
☐ Both

Information regarding complaints of the wrist

3. Do you currently have complaints of the wrist indicated in the question above?

☐ No (go to question 5)
☐ Yes

4. What is your pain score at this moment? Zero indicates no pain at all, 10 indicates worse pain.

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
0									10

5. For how long did you already had complaints before your first visit to our hospital?

☐ < 1 month
☐ 1–3 months
☐ 3–6 months
☐ 6 months–1 year
☐ > 1 year

6. What was your pain score at the first visit to our hospital? Zero indicates no pain at all, 10 indicates worse pain.

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
0									10

7. Did you follow a wrist exercise program, recommended by our hospital?
   - ☐ No (go to question 10)
   - ☐ Yes

8. In which practice did you receive treatment regarding the complaints of your wrist?

………………………………………………………………………………………………..

………………………………………………………………………………………………..

9. For how long did you receive treatment in this practice?
   - ☐ < 1 month
   - ☐ 1–3 months
   - ☐ 3–6 months
   - ☐ 6 months–1 year
   - ☐ > 1 year

10. How many treatments of the wrist exercise program have you followed?
   - ☐ < 5 treatments
   - ☐ 5–10 treatments
   - ☐ 10–15 treatments
   - ☐ > 15 treatments

11. What kind of exercises have you followed during the wrist exercise program? (multiple answers allowed)

Exercises focused on:
   - ☐ A correct position of wrist and hand (e.g., "straight wrist" during lifting, supportive bandage, recommendations regarding position of the hand)
   - ☐ Improvement in strength (e.g., squeeze ball, exercise band)
   - ☐ Stabilization of the wrist (e.g., "powerball," movement with dumbbell with resistance, stabilization of a stock)
   - ☐ Coordination (e.g., rolling of marbles, catching balls)
   - ☐ Complex movements (e.g., rhythmic movement, drumming, balance exercises, "exercises with eyes closed")
   - ☐ Mobility and flexibility (e.g., exercise extreme positions, passive movement of wrist)
   - ☐ Pain control and perception (e.g., medication, TENS, injections, "dry needling")
   - ☐ Massage/manipulation (e.g., "straighten" of the wrist bones)
   - ☐ Infrared or ultrasound
   - ☐ Other, namely ……………………………………………………………………………………
     ………………………………………………………………………………………………………

12. What was the effect of the exercise program you followed, immediately after the treatment was finished? Zero means no effect, 10 is the maximum effect.

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

0 10

13. Did you receive additional treatment for your wrist after the exercise program?

☐ No (go to question 15)

☐ Yes

14. I received additional treatment, namely

☐ Operation

☐ Other treatment by physical therapist

☐ Other, namely ....

....

15. Did you suffer from a new trauma of your wrist which increased the complaints of your wrist, after you finished the wrist exercise program?

☐ No

☐ Yes, namely ....

....

16. What is your current occupation/job?

....

17. Did you have to adjust your occupation/job due to the complaints of your wrist?

☐ No

☐ Yes, namely ....

....

18. I am able to perform my occupation/job:

☐ Fully

☐ Adapted, due to the complaints of my wrist

☐ I am not able to perform my occupation/job, due to the complaints of my wrist

☐ Other, namely ....

....

19. The wrist exercise program I followed:
    - ☐ Had no influence on my occupation/job
    - ☐ Due to the wrist exercise program, I could return to my old occupation/job
    - ☐ Due to the wrist exercise program, I needed less adaptions

VIDEO LEGENDS

Video 1. Wrist cineradiography, PA view. Normal wrist movement. Maximum ulnar deviation to maximum radial deviation.

Note:

- The PCR flexes during radial deviation and extends during ulnar deviation.
- All movements in the PCR are perfectly synchronous.

Video 2. Wrist cineradiography, PA view. Dynamic SLD. Maximum ulnar deviation to maximum radial deviation.

Note:

- The scaphoid moves asynchronously with the lunate during ulnar deviation, the SL distance subtly increases during ulnar and radial deviation.
- The SL distance is not at its widest in maximum ulnar deviation.

Video 3. Wrist cineradiography, PA view. LTD. Maximum ulnar deviation to maximum radial deviation.

Note:

- The triquetrum and lunate do not move synchronously.
- During radial deviation the triquetrum moves more distally than the lunate.

Video 4. Wrist cineradiography lateral view. Normal wrist movement. RUD and extension to flexion.

Note:

- The scaphoid flexes synchronously with the lunate during radial deviation and flexion.
- The lunate moves easily through the 0° line of the radiolunate angle during flexion.

Video 5. Wrist cineradiography, lateral view. Dynamic SLD. Extension to flexion.

Note:

- The lunate does not flex synchronously with the scaphoid.
- During flexion the lunate does not pass the 0° line of the RL angle as easily as in a normal wrist.

Video 6. Wrist cineradiography, lateral view. Dynamic SLD. Maximum ulnar deviation to maximum radial deviation.

Note: The lunate does not flex fully during radial deviation.

Video 7. Wrist cineradiography, PA view. Lichtman test.

- Palmar translation is applied so that the PCR is flexed.
- The wrist is axially loaded and ulnarly deviated.

- The test result is positive for a palmar CIND if a catch-up clunk in the PCR occurs and reproduces the patient's symptoms.
- If the clunk does not reproduce the patient's symptoms, the wrist can be diagnosed as a hypermobile or lax wrist.
- This test can be performed in the PA and lateral views.

Video 8. Wrist cineradiography, lateral view. Anterior and posterior drawer test, normal wrist.

- Dorsally directed pressure while longitudinal traction is applied to the wrist.
- When translating the DCR into a palmar direction (anterior drawer test), a palmar capitolunate subluxation suggests a palmar CIND (not present in this video).
- By translating the DCR in a dorsal direction (posterior drawer test), a dorsal subluxation of the PCR and almost complete dorsal subluxation of the capitate from the lunate, in which the capitate may be moved beyond the dorsal lip of the lunate, can be seen (not present in this video).
- The diagnosis CLIP is made if instability at the capitolunate joint reproduces the patient's symptoms.

Video 9. Wrist cineradiography, PA view. Static SLD. Maximum radial deviation to ulnar deviation. Note: The scaphoid moves from the lunate during ulnar deviation, while the lunate remains stationary. Additionally, the lunate does not extend during ulnar deviation. During extreme radial and ulnar deviation the lunate may move due to the position of the wrist in the lunate fossa. This is not because the lunate moves along with the scaphoid.

Video 10. Wrist cineradiography, lateral series. Static SLD. Extension to flexion. Note: The scaphoid flexes during flexion, while the lunate stays stationary and in an extended position. During extreme flexion of the hand, the lunate will flex due to the position of the wrist. This is not because the lunate moves along with the scaphoid.

NEDERLANDSE SAMENVATTING (DUTCH SUMMARY)

De pols is een complex gewricht waarbij er stabiliteit bestaat door een balans tussen de handwortelbeentjes (ossa carpalia), de polsligamenten en de pezen van de onderarm.

Instabiliteit van de carpalia kan ontstaan door hyperlaxe polsligamenten of als er sprake is van letsel van een of meer ligamenten in de pols. Sommige vormen van carpale instabiliteit kunnen leiden tot uitgebreide artrose, met als gevolg pijnklachten en een verminderde functie van de pols.

Carpale instabiliteit is onder te verdelen in drie groepen, namelijk; een dissociatieve vorm "carpal instability dissociative (CID) en een niet dissociatieve vorm "carpal instability non-dissociatieve" (CIND) of een combinatie van beiden "carpal instability combined or complex" (CIC).

CID is gedefinieerd als een transarticulaire en/of transossale dissociatie in de proximale of distale carpale rij. De meest bekende vorm is een non-union van het scaphoid en een scapholunaire dissociatie (SLD). Een SLD kan weer opgedeeld worden in drie stadia: predynamisch, dynamisch en statisch.

Omdat de onderlinge relatie tussen de carpalia in rust niet verstoord is bij een (pre) dynamisch SLD is de diagnose niet goed te stellen met behulp van een röntgenfoto. Dit geldt wel voor het verder gevorderde stadium van een statisch SLD waarbij onderlinge relatie tussen de carpalia ook in rust is verstoord.

Voor de patiënt is het belangrijk om een SLD in een zo vroeg mogelijk stadium te diagnosticeren om zo functieverlies te minimaliseren.

De polsvideo is het enige dynamische röntgenonderzoek dat de carpalia real-time in beeld kan brengen terwijl de pols in meerdere richtingen wordt bewogen. Hierdoor zijn de bewegingen van de carpalia goed in beeld te brengen en is een afwijkende beweging tussen onder andere het scaphoid en lunatum goed te zien. Op deze manier kan een (pre) dynamisch SLD worden gediagnostiseerd.

In dit proefschrift focussen wij ons op het diagnosticeren van een SLD door het gebruik van de polsvideo.

In **hoofdstuk 2** worden de verschillende vormen van een CIND besproken. Tevens wordt er dieper in gegaan op de pathomechanica, klinische presentatie, diagnostische work-up en behandelingen van de verschillende vormen van CIND.

In **Hoofdstuk 3** hebben wij een protocol gemaakt voor het diagnosticeren van de verschillende vormen van carpale instabiliteit. Dit protocol is gebaseerd op de uitgebreide ervaring die het AMC heeft in het maken van polsvideo's, de uitkomsten die gepresenteerd zijn in **hoofdstukken 4, 5, 6** en de huidige literatuur.

Hoofdstuk 4 betreft een retrospectieve studie die werd uitgevoerd in een centrum met zeer veel expertise in het maken van polsvideo's. Hierbij werden polsvideo's van patiënten die verdacht waren voor een SLD bekeken en vergeleken met de gouden standaard, arthrotomie en/of een polsscopie. Er werd voor de polsvideo een sensitiviteit van 90% en specificiteit van 97% gevonden voor het diagnosticeren van een SLD.

Om te controleren of er vergelijkbare resultaten gevonden worden voor de polsvideo in een centrum dat minder expertise heeft in het maken van polsvideo's, is het onderzoek herhaald in een ander centrum. Dit onderzoek wordt gepresenteerd in **Hoofdstuk 5** en laat zien dat er vergelijkbare resultaten gevonden werden voor het diagnosticeren van een SLD met behulp van de polsvideo (sensitiviteit 96% en specificiteit 89%).

In **hoofdstuk 6** hebben we uitgezocht wat de inter- en intra-observer variabiliteit zou zijn voor het diagnosticeren van een SLD met behulp van de polsvideo. We hebben dit onderzocht met een radioloog, traumachirurg en een handchirurg. De inter-observer variabiliteit was uitstekend (k = 0.84) en de intra-observer variabiliteit was goed tot uitstekend (k = 0.72 – 0.80).

In **hoofdstuk 7** hebben we een pilotstudie uitgevoerd naar het polsscholingsprogramma voor patiënten met een palmaire CIND, de meest voorkomende vorm van CIND. De uitkomsten lieten veelbelovende lange termijn uitkomsten zien voor patiënten die het polsscholingsprogramma hadden gevolgd.

Hoofdstuk 8 betreft de discussie aangaande dit proefschrift.

DANKWOORD/ACKNOWLEDGEMENTS

Om te beginnen wil ik mijn promotiecommissie bedanken.

Mijn promotores:
Chantal,
Daar is hij dan, mijn proefschrift zoals ik had beloofd voordat ik de opleiding in kwam. Weliswaar 1,5 jaar later dan gepland, maar hij is er wel! Woorden kunnen niet beschrijven hoe dankbaar ik ben voor alles wat je voor mij gedaan hebt. Je bent en zal altijd een inspiratie voor mij blijven. Ik voel mij geprezen dat ik jou als opleider heb mogen meemaken. Je oneindige energie en enthousiasme zijn zeer aanstekelijk. En ik heb je echt als een tweede moeder beschouwd. Niet alleen tijdens de opleiding heb ik op vakinhoudelijk gebied ontzettend veel van je geleerd, maar ook zeker op persoonlijk vlak. Naast de momenten van inspanning en opperste concentratie tijdens het werk, heb ik ook zo genoten van de kleine momenten na werk. Op vrijdag even met een biertje de week nabespreken doet zoveel goeds soms. En dan heb ik het niet eens over de mooie kerstavonden bij jou en Jan thuis. Zonder jou was ik nooit de plastisch chirurg geworden die ik nu ben, maar had ik ook nooit dit proefschrift kunnen afronden. Ik ben je eeuwig dankbaar!

Mario,
Ik wil je ontzettend bedanken voor je tijd, energie, kritische blik en kennis die jij in dit proefschrift hebt gestopt. Als radioloog kijk je toch net even anders tegen bepaalde stukken aan dan als plastisch chirurg. Tijdens de opleiding heb ik zo genoten van je op de woensdagmiddag besprekingen, je kon deze zo leuk en leerzaam maken. Ik heb ontzettend veel bewondering voor je, onder andere omdat je zoveel dingen zo helder en duidelijk kan uitleggen. Alle AIOS radiologie die jou meemaken tijdens hen opleiding mogen in hen handen knijpen met zo een opleider. Het bordje op je kamer met je eerste onderzoekje over de polsvideo's zal ik nooit vergeten. Naast de tijd en energie die jij in de polsvideo's in het AMC hebt gestopt, en hoeveel patiënten maar ook plastisch chirurgen hier profijt van hebben gehad is ontelbaar. Het heeft mij gedreven om dit werk waar jij een zeer grote bijdrage aan hebt geleverd te bundelen tot dit proefschrift.

Mijn copromotor:
Simon,
Ik weet niet zo goed waar ik moet beginnen. Wat heb jij mij veel geleerd. Over het vak, maar misschien nog wel meer over mezelf. Je enthousiaste heeft ervoor gezorgd dat ik als co-assistent mijn pijlen volledig ging richten om in opleiding te komen voor de plastische chirurgie. Zo besloot ik een onderzoek te starten in de hand pols chirurgie omdat jij nog wel iets voor mij had liggen; het uitzoeken van alle polsvideo's die ooit gemaakt zijn in het AMC. Hoeveel uur ik wel niet in dat kleine hokje naast het secretariaat heb doorgebracht

met die video's zal ik nooit vergeten, je wordt bedankt! Uiteindelijk heeft dit onderzoek wel geleid tot dit proefschrift. Ik wil je bedanken voor al je kennis en kunde die je mij hebt bijgebracht tijdens de opleiding. Daarnaast heb ik ook zoveel geleerd hoe je om moet gaan met alle randzaken van het dokter zijn. Je nooit laten opjagen door tijd, maar elke patiënt de aandacht geven die hij/zij verdient. Altijd rustig blijven en problemen systematisch analyseren. Naast het vakinhoudelijke heb ik ook zo veel meer geleerd op persoonlijk gebied. Ik heb zo genoten van je vakantieverhalen tijdens een kop koffie in de ochtend op het voetenplein, maar ook van al je verhalen over je hobby's; het klussen aan je VW-busje, je motor en geluidsboxen. Ik moest wel altijd even een half uur extra plannen voor onze persoonlijke afspraken, anders hadden we nooit tijd om tot het echte werk over te gaan. Maar dat deed ik met plezier.

Beste Simon, ik ben je eeuwig dankbaar. Net zoals Chantal heb jij ook een zeer belangrijke bijdrage geleverd aan de plastisch chirurg die ik nu ben. Je bent absoluut een bron van inspiratie voor mij!

De overige leden van de promotiecommissie
Miryam,
Ik ben je dankbaar voor alles wat je me hebt geleerd tijdens de opleiding. De structuur die je in bracht tijdens de gekoppelde stages heeft mij enorm goed gedaan. Ik heb veel bewondering hoe je de zware taak als opleider van Chantal hebt overgenomen.
Uiteindelijk ben ik je eerste assistent geweest die daadwerkelijk de opleiding bij je mocht afronden en daar ben ik trots op!

Daarnaast wil ik prof. Oostra, prof. Tol, prof. Harlaar, dr. van Dijke en prof. Nollet bedanken voor het nakijken en beoordelen van dit proefschrift.

Niels,
Ik wil je bedanken voor de grote bijdrage die je hebt geleverd aan dit proefschrift. Met name in de eerste jaren heb je mij zo geholpen om alles goed op te zetten en kritisch te kijken naar elk stuk. Je oneindige energie is echt bijzonder. Wat mij enorm heeft geïnspireerd is je enorme toewijding aan een onderwerp als je erdoor gefascineerd wordt, zoals de hand-pols chirurgie.

Ik vond het zo ontzettend jammer dat je weg ging uit het AMC, weet zeker dat ik nog zoveel meer van je had kunnen leren. Zeker gezien de samenwerking tussen de plastische chirurgie en trauma chirurgie in het AMC. Ik hoop in de toekomst nog een keer met je samen te mogen werken.

Ik wil al mijn mede-auteurs bedanken voor al hun energie en tijd die zij in dit proefschrift hebben gestoken. Zonder jullie was dit proefschrift er niet geweest.

Oren en Annekatrien,
Dank jullie wel voor de mooie en leerzame stages die ik bij jullie heb mogen volgen. Het was niet alleen leerzaam, maar ook zeker gezellig en leuk! Ook jullie hebben bijgedragen aan de plastisch chirurg die ik nu ben geworden, en daar ben ik jullie ontzettend dankbaar voor!

Maatschap plastische chirurgie in het RKZ, Spaarne en Blooming PC,
Ik heb zo ontzettend veel geleerd in het jaar dat ik bij jullie in opleiding was. Niet alleen vakinhoudelijk was het leerzaam met stages in de hand-pols chirurgie, het brandwondencentrum en de cosmetiek. Maar ook vond ik het leerzaam om te zien hoe jullie als maatschap werkten en wat voor een hecht team jullie zijn. Het jaar was heftig met het overlijden van Paris en ik heb ontzettend veel respect voor jullie hoe jullie hiermee zijn omgegaan. Jullie hebben een mooi team met ontzettend veel inspirerende chirurgen. Dank voor alles!

Plastisch chirurgen in het AvL,
Ik heb in de tijd bij jullie zo veel geleerd over mammareconstructies en daar ben ik jullie zeer dankbaar voor. De donderdagmiddag middag was altijd kritisch maar ook zeker gezellig en leerzaam!

Lieve assistenten waarmee ik de plastische opleiding heb gevolgd. Dank voor de gezellige tijd die ik met jullie heb gehad tijdens de opleiding. We hebben samen zitten stressen voor elk examen en lastige ingreep, geklaagd over wat er allemaal beter moest maar vooral gefeest en plezier gemaakt.

Vera en Mario, dank dat jullie alle jaren voor mij en het hele team in het AMC klaar stonden. Ongelooflijk hoe belangrijk jullie zijn voor het AMC!

Geert, dank voor het op het laatste moment uitzoeken van de stralingsbelastingen.

Paul,
Mijn opleider in de vooropleiding. Je hebt me echt alle kneepjes van de algemene heelkunde bijgebracht, maar uiteraard ook hoe je goed een bibliotheek moest bijhouden ;). Ik had er altijd zoveel bewondering voor dat je je vleugels boven de assistenten hield maar toch ook kritisch kon zijn. Je motto's zijn mij altijd bijgebleven, "opereren = registreren", "je moet opereren en niet compenseren". En uiteraard heb ik enorm genoten van de pre-summer parties bij jou en Marloes thuis. Beste Paul, dank dat je mijn opleider wilde zijn. "Wat een k*t leven!"

Alle assistenten en chirurgen van het Flevoziekenhuis. Jullie stonden er in het begin van mijn opleiding en hebben ervoor gezorgd dat de vooropleiding niet alleen leerzaam was, maar ook echt een feestje! Ik zal deze tijd nooit vergeten.

Anne, Esther, Ernst, Mischka en Sjoerd,
Wat hebben we een mooie tijd gehad met Kortjakje. Vooral de avonden voor de grote dag, de feestjes en de etentjes die we hebben meegemaakt zullen mij altijd bij blijven. Hoop dat we nog geregeld dit soort avonden over doen!

Aan mijn maten van het Diak,
Wat ben ik ontzettend vereerd en blij dat ik nu deel uitmaak van de mooiste maatschap van Nederland. Ik hoop dat we altijd zo vooruitstrevend zullen blijven en dat we blijven denken in oplossingen en kansen. Ik heb zin in de vele etentjes, feestjes, ski-vakanties, weekendjes weg, congressen, cursussen en festivals samen de komende 30 (?!) jaar.

Alle assistenten en chirurgen waarmee ik in het SLAZ (nu OLVG West) gewerkt heb, dank voor de mooie leerzame tijd. Ongelooflijk hoeveel je eigenlijk nog moet leren als je net co-assistent af bent. Blij dat ik zoveel heb mogen leren in het ziekenhuis waarin ik ben geboren.

Al mijn trainers, coaches en teamgenoten van Hurley, jullie betekenen veel voor me en hebben mij grotendeels gevormd. Zal jullie nooit vergeten.

Gasten van Amsterdam H4, dank voor de mooie jaren. Ben blij dat ik mijn laatste jaren als hockeyer met jullie heb mogen doorbrengen.

Huub, Hens, Flo, Lam, Andy en de rest van de boys. Dank voor de vele avonden, feesten, vakanties en bachelors die we hebben mogen meemaken. Jullie zorgden voor ontspanning in drukke tijden. Ik hoop dat we nog veel meer mooie herinneringen zullen maken!

Max, Snor en Flamoes, dank dat jullie mij hebben omarmd in de familie. Veel dank!

Melissa, Lawrence en Victor, al zo lang geleden zijn jullie in mijn leven. Jullie zijn familie!

Pap,
Bedankt dat je zo’n fijn luisterend oor bent en dat je de taal van het promotieonderzoek verstaat.

Mam,
Dank voor alle jaren, dank voor hoeveel je wel niet voor mij hebt gedaan in mijn leven, dank dat je altijd voor me klaar stond en staat. Dank dat je me hebt gemaakt tot wie ik nu ben. Ik kan in woorden niet omschrijven hoe dankbaar ik je ben en hoeveel ik van je hou.

Erwin,
Dank dat je altijd een goede trouwe broer voor mij bent waar ik altijd op terug kan vallen.

Elise,
Al ruim 11 jaar mijn vrouw(tje) en ben nog steeds zo ongelooflijk gelukkig met je. Zonder jouw support en steun was dit proefschrift er niet geweest. Je hebt best wat moeten laten als ik weer eens dienst had, moest hockeyen of aan het proefschrift moest zitten. Ik ben ontzettend trots dat jij de moeder van onze kinderen bent, je bent de beste! Dank dat je bij me bent en dat je me steunt, altijd. Ik kijk uit naar een mooie en gezonde toekomst samen!

Louis,
Ik ben zo trots op je. Ik hoop dat je je vrolijkheid, liefde, wilskracht, energie en nieuwsgierigheid voor altijd zult houden. Lieve Lou, papa houdt ontzettend veel van je en ik zal er altijd voor je zijn!

Sophia,
Ongelooflijk wat voor strijder je bent. Ondanks de heftige start waarin papa en mama niet zoveel als we wilden bij je konden zijn, zie je er zo blij, gelukkig en tevreden uit. Je geeft ons zoveel liefde! Ik hoop dat je gelukkig blijft. Ik zal er in ieder geval alles aan doen, altijd van je houden en klaar voor je staan.

PORTFOLIO

General Courses		Year
Advanced Trauma Life Support	New York, USA	2013
AO Fracture Management – basic principles	Davos, Switzerland	2013
AMC Hand & Wrist workshop, Smith & Nephew	Amsterdam	2013
Fundamental Critical Care Support	Bilthoven	2014
Radiation protection training – basic, level 4A/M	Amsterdam	2015
Canniesburn flap & perforator course	Glasgow, Scotland	2016
Basic Microsurgery training course	New York, USA	2017
AO Hand Fixation for surgeons	Leeds, England	2017

Specific courses	Year
The European Board of Plastic Reconstructive and Aesthetic Surgery (EBOPRAS)	2018

Seminars, workshops and master classes

Weekly department seminars AMC	2009 – 2018
Journal Club AMC	
» NVPC meetings	2009 – 2019
» NVvH meetings	2017 – 2019
» NVEPC meeting	2019
» FESSH meetings	2014, 2017, 2018

Oral presentations

(Mid)carpal instability
AMC, scientific meeting, 2018, Amsterdam, the Netherlands
Long-term functional results of a wrist exercise program for patients with midcarpal instability. *Federation of European Societies for Surgery of the Hand (FESSH), 2017, Budapest, Hungary*

Diagnosing scapholunate dissociations. Flevoziekenhuis, local scientific meeting, 2013, Almere, the Netherlands

Infections after skin sparing mastectomy with direct reconstruction. Flevoziekenhuis, local scientific meeting, 2013, Almere, the Netherlands

De polsvideo in het diagnosticeren van een SLD. *The Dutch Society for Plastic Surgery (NVPC), 2012, Groningen, The Netherlands*

Intraobserver and interobserver variability in diagnosing scapholunate dissociation by cineradiography.
Federation of European Societies for Surgery of the Hand (FESSH), 2014, Paris, France

Portfolio (continued)

	Year
Poster presentation	
Accuracy and consequences of 3D fluoroscopy in upper and lower extremity fracture treatment. A Systematic Review. *Dutch Surgical Society (NVvH), 2010, Nijmegen, The Netherlands*	
Teaching	
Research supervising	
C.M.M. Horsten, medical student	2018
M.G.A. de Roo, medical student	2016
Publications	
Lokin JLC, **Sulkers GSI**. De rol van dynamische beeldvorming bij carpale instabiliteit. IMAGO. September 2018: 23 – 30.	
Mulders MAM, **Sulkers GSI**, Videler AJ, Smeulders MJC, Strackee SD. Long-term functional results of a wrist exercise program for patients with palmar midcarpal instability. Journal of Wrist Surgery. 2018, 7: 211 - 218.	
Sulkers GSI, Strackee SD, Schep NWL, Maas M. Wrist cineradiography: a protocol for diagnosing carpal instability. Journal of Hand Surgery European Volume. 2018, 43:174 - 178.	
Cheriex KCAL, **Sulkers GSI**, Terra MP, Schep NWL, van Aard BJPL, Strackee SD. Scapholunate dissociation; diagnostics made easy. European Journal of Radiology. 2017, 92: 45 – 50.	
Sulkers GSI, Schep NWL, Maas M, Strackee SD. Intraobserver and interobserver variability in diagnosing scapholunate dissociation by cineradiography. Journal of Hand Surgery American Volume. 2014, 39: 1050-1054.	
Sulkers GSI, Schep NWL, Maas M, Strackee SD. Diagnosing scapholunate dissociation. Dutch Journal of Handtherapy. 2014, 23.	
Sulkers GSI, Schep NWL, Maas M, van der Horst CMAM, Goslings JC, Strackee SD. The diagnostic accuracy of wrist cineradiography in diagnosing scapholunate dissociation. Journal of Hand Surgery European Volume. 2014, 39: 263 – 271.	
Beerekamp MSH. **Sulkers GSI**, Ubbink DT, Maas M, Schep NWL, Goslings JC. Accuracy and consequences of 3D fluoroscopy in upper and lower extremity fracture treatment. A Systematic Review. European Journal of Radiology. 2012, 81: 4019 – 4028.	

Portfolio (continued)

	Year
Submitted Van Hoorn BT, Rossenberg L, Jacobs X, **Sulkers GSI**, van Heijl M, Ring D. Clinician rather than patient factors affects discussion of treatment options in hand surgery. The Journal of Bone and Joint Surgery.	
MEMBERSHIPS » Dutch Society for Plastic Surgery (NVPC) » The European Board of Plastic Reconstructive and Aesthetic Surgery (EBOPRAS) » Dutch Society for Hand Surgery (NVvH) » Dutch Society for Esthetic Plastic Surgery (NVEPC)	

CURRICULUM VITAE

George Sulkers is born in Amsterdam on February 2nd. In 2004 he graduated from the Hervormd Lyceum Zuid and started his medical study that year at the Academic Medical Center (AMC) in Amsterdam. During his high school and medical study he played field hockey on a high level, represented national youth teams and won some European Youth Championships. After he graduated from medical school he stopped playing hockey and started to focus on his medical career. During medical school he already started with some research at the trauma unit at the AMC, but when he decided to become a plastic surgeon he switched from department and started with research what appeared to be the start of this thesis. His first job was at the general surgery department at the Saint Lucas Andreas Hospital (nowadays known as OLVG West), the hospital in where he was born. After this year he started with his plastic-, reconstructive- and handsurgery residency. The biggest part of this thesis was written during his residency. The first two years of his residency he worked as a general surgery resident at the Flevohospital which was followed by four years of plastic surgery residency at the AMC, Antoni van Leeuwenhoek hospital, Spaarne Gasthuis and Red Cross Hospital. The last months of his residency he followed a visiting fellowship at the Kaplan Institut in Barcelona, Spain. He works now as a plastic surgeon at Bey by Bergman clinics and the Diakonessenhuis in where he focusses on handsurgery, breastreconstruction, oncodermatology and cosmetic surgery.