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# Structure and blood supply of the postero-superior part of the shoulder joint capsule with implementation of surgical treatment after anterior traumatic dislocation

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## Author's contribution

I. The author took part in the gross anatomical research and was the main person responsible for writing the manuscript.
II. The author was responsible for the clinical analysis of the anatomical structures.
III. The author took part in all stages of the study and was the main person responsible for writing the manuscript.
IV. The author developed the surgical technique and was the main person responsible for writing and providing images for the manuscript.

# ABBREVIATIONS

| | |
|---|---|
| ACL | Anterior Cruciate Ligament |
| APTRCT | Articular-Sided Partial Thickness Rotator Cuff Tear |
| ATSD | Anterior Traumatic Shoulder Dislocation |
| ASES | American Shoulder and Elbow Surgeons |
| CT | Computed Tomography |
| GHJ | Glenohumeral Joint |
| GCL | Glenocapsular Ligament |
| HSL | Hill-Sachs Lesion |
| ISP | Infraspinatus |
| MRI | Magnetic Resonance Imaging |
| ROM | Range of Motion |
| SCOI | Southern California Orthopedic Institute |
| SSP | Supraspinatus |
| TM | Teres Minor |
| 3DCT | Three-Dimensional Computed Tomography |

# 1. INTRODUCTION

Anterior traumatic shoulder dislocation (ATSD) is the most frequent type of joint dislocation in the human body. During anterior glenohumeral joint (GHJ) dislocation, the humeral head moves anteriorly, and the postero-superior part of it engages with the antero-inferior rim of the scapular glenoid. Most commonly, the antero-inferior capsulolabral structures are injured, with or without a fracture of the antero-inferior scapular glenoid and osteochondral damage on the postero-superior part of the humeral head, the so-called Hill-Sachs lesion (HSL) (Hill and Sachs, 1940). According to the literature, the incidence of HSL is from 58 to 100% after ATSD (Wheeler, 1989; Norlin, 1993; Hintermann et al., 1995; Taylor et al., 1997). Concomitant rotator cuff injuries after GHJ dislocation have been described in patients older than 40 years in 35–86% of cases (Hintermann et al., 1995; Pevny et al., 1998; Hovelius et al., 2008). In patients younger than 30 years of age, rotator cuff injuries are reported as articular-sided partial thickness injuries involving the superior part of the rotator cuff. The incidence has been reported to be 3% to 6% (Kim et al., 2010; Shin et al., 2016).

The postero-superior GHJ area is clinically important in young overhead athletes, as impingement can occur with the postero-superior capsulolabral part of the glenoid (Walch et al., 1992). In symptomatic cases, it was found during arthroscopic inspection that 95% of patients with this kind of impingement had superficial intra-articular rotator cuff tears in the aforementioned location (Paley et al., 2000).

Anatomically, the superior capsular area with the rotator cable (anatomic term *ligamentum semicirculare humeri*) is tightly connected with the supraspinatus tendon (SSP) (Burkhart et al., 1993; Kolts et al., 2000; Kask et al., 2008). Studies suggest that it is of clinical importance as an anatomic landmark when treating massive rotator cuff tears (Mochizuki et al., 2009). This anatomical complex also explains the previously described rotator cuff "suspension bridge" theory (Burkhart et al., 1993), which is supported by cadaveric studies (Halder et al., 2002). It has been reported that the integrity of the superior capsule and rotator cable area without rotator cuff tears significantly affects the anterior and inferior translation of the GHJ (Ishiara et al., 2014; Pinkowski et al., 2017).

Meanwhile, the vascularity of the postero-superior part of the GHJ is an important factor in rotator cuff tears (Fukuda et al., 1990; Determe et al., 1996; Lõhr and Uhtoff, 2007). The postero-superior capsulomuscular blood supply is provided by the circumflex scapular and posterior circumflex humeral arteries (Andary and Petersen, 2002; Naidoo et al., 2014; Põldoja et al., 2017).

The recurrence rate after conservative treatment of first-time ATSD is very high, especially in young, active patients, ranging from 77% to 94% (Wheeler et al., 1989; Hintermann et al., 1995; Larrain et al., 2001; Robinson et al., 2006). The recurrence rate depends on the presence of bone deficiency in the injured areas. Surgical treatment after first-time ATSD is refixation of the ruptured antero-inferior capsulolabral structures with or without a fractured glenoid. Still, the recurrence rate after surgical treatment in cases without any bone defect is up to 6.5% in young athletes (Burkhart and de Beer, 2000). Thus, considering the findings of cadaveric studies and clinical observations, postero-superior capsular integrity seems to play a crucial role and appears also to contribute to antero-inferior stability.

Additionally, the postero-superior part of the GHJ is important in chronic anterior shoulder instability cases. Recurrent anterior shoulder dislocation increases the depth and size of HSL (Cetik et al., 2007; McMahon et al., 2013). If the HSL defect is large and engages with the antero-inferior glenoid, filling of the postero-superior humeral head defect with the postero-superior capsule and infraspinatus (ISP) tendon has been suggested, in addition to the restoration of the antero-inferior capsulolabral structures (Purchase et al., 2008). This surgical technique, called “remplissage” (Wolf and Pollack, 2004), is useful in recurrent anterior shoulder dislocation cases. The focus of improving the remplissage technique has been on achieving a strong fixation, however, without attention paid to the vascularity of the postero-superior part of capsulomuscular structures.

# 2. LITERATURE REVIEW

## 2.1. Structures in the postero-superior part of the shoulder joint

### 2.1.1. Insertion area of the rotator cuff tendons (Footprint area)

According to Clark and Harrymann (1992), it can be difficult to separate the ISP and SSP tendons in the insertion area on the greater tuberosity of the humerus. Ruotolo et al. (2004) reported that on the footprint area of the SSP and ISP, the tendons run parallel to the superior and supero-posterior facets of the greater tuberosity of the humerus and have square- or trapezoid-shaped insertion areas. Minagawa et al. (1998) observed overlapping areas of the ISP and SSP tendons on the footprint and found that the area of the ISP footprint is wider. Mochizuki et al. (2008) stated that the SSP insertion area is smaller and more anterior than the classic description suggests, that the SSP tendon is partially covered by the ISP tendon. Furthermore, the length of the capsule on the insertional area from the cartilage to tendon was 4.5 mm. Lumsdaine et al. (2015) confirmed these anatomical findings and the relationship between the SSP and ISP tendons. Furthermore, they did not find any statistical correlations between the size of the footprint with the side of the extremity, nor with the age, sex and height of the patient.

### 2.1.2. Postero-superior joint capsule

The superior shoulder joint capsule starts laterally with the insertion of the SSP and ISP tendons on the footprint area. Anteriorly, it also involves the coracohumeral ligament, the superior glenohumeral ligament, and the long head of the biceps tendon (Gohlke et al., 1994). Clark and Harryman (1992) found in dissected specimens a complex network of fibers running into the superior capsule and extended anteriorly over the biceps tendon with fixation on the lesser tuberosity and posteriorly beneath the SSP and ISP, forming a flat band of approximately 1 cm. This thickened fibrous tissue runs posteriorly and perpendicular to the fibres of the SSP and ISP tendons. Burkhart et al. (1993) named this the rotator cable described it as a 2.59 times thicker structure compared to the capsule, with an average width of 12.05 mm in the superior capsule. Detailed descriptions of the rotator cable have been achieved through anatomic dissection of embalmed and unfixed specimens by Kolts et al. (2002). They describe the rotator cable as a constant anatomical structure, a curved intracapsular ligament in the superior part of the GHJ capsule, under the SSP and ISP tendons, and was named semicircular humeral ligament.

In line with this, Kask et al. (2008) provide an MRI description of the rotator cable in cadavers. Gyftopoulus et al. (2013) found a clear correlation between

MRI, arthroscopy and gross anatomic findings of intact rotator cable specimens in a cadaveric study. Macarini et al. (2011) found in an MRI study that the rotator cable is more easily detectable on oblique coronal scans in 62% of patients, without differences between males and females or between different ages. Morag et al. (2006) have demonstrated the existence of the rotator cable using ultrasonography.

### 2.1.3. Vascularity

Rothman and Park (1965) found that six arteries were responsible for supplying the rotator cuff. In 100% of specimens, the suprascapular, anterior circumflex and posterior circumflex humeral arteries were found. According to Ling et al. (1990), Garza et al. (1992) and Notarnicola et al. (2012), the rotator cuff tendons are supplied by the suprascapular, thoracoacromial, scapular circumflex, and anterior and posterior circumflex humeral arteries. Cooper et al. (1992) found that branches from the suprascapular, circumflex scapular and posterior circumflex humeral arteries were responsible for the capsular vascularization of the whole shoulder joint.

Chansky and Ianotti (1991) found that the posterior circumflex humeral artery was responsible for posterior rotator cuff vascularization. The blood supply of the subacromial bursa has been described in an anatomic and arthroscopic study by Yepes et al. (2007); however, the study did not involve the blood supply of the rotator cuff tendons on the bursal side. According to Põldoja et al. (2017), the posterior part of the bursa and the ISP and teres minor (TM) tendons on the bursal side are supplied by the posterior circumflex humeral artery.

Löhr and Uhthoff (1990), in a histologic study, and Rudzki et al. (2008) and Adler et al. (2008), in contrast-enhanced ultrasound studies, found that a hypovascular zone is located on the articular part of the SSP tendon, but not on the bursal side. Andary and Petersen (2002) reported that the hypovascular zone is located in the joint capsule and not in the rotator cuff tendons.

Levy et al. (2008), in a laser Doppler flowmetry study, compared vascularization of a normal rotator cuff with impinged and ruptured ones and found that an impinged cuff was hypovascular and a torn cuff hypervascular. Decreased vascularity of both pathologic and intact SSP tendons was confirmed by Kathikeyan et al. (2015). Chansky and Ianotti (1991), Löhr and Uhthoff (2007). Biberthaler et al. (2003) and Pandey and Willems (2015) have reported that poor vascularity can induce degenerative changes and tendon ruptures of the rotator cuff. In a review study, Hegedus et al. (2010) summarized that the relationship between vascularity, age and degeneration of the rotator cuff is largely unclear. However, impingement may cause hypovascularity, but contrary to this, increased vascularity is normal for smaller tears.

## 2.2. Clinical aspects of the superior and postero-superior part of the shoulder joint

### 2.2.1. Superior capsular damages

The superior capsule is tightly connected with the rotator cuff tendons (Clark et al., 1990). The importance of the superior capsule and the rotator cable was described by Burkhart in 1993. The rotator cable creates a stress-shielding effect from the rotator cuff tendon to the superior capsule and functions in the presence of rotator cuff tears as a loaded suspension bridge cable. This suspension bridge phenomenon was biomechanically tested by Halder et al. in 2002. The insertion area of the rotator cable is an important landmark during repair of massive rotator cuff tears (Mochizuki et al., 2009). Mesiha et al. (2013) demonstrated in a cadaver study that the anterior attachment of the rotator cable is the primary load-bearing structure within the SSP tendon for force transmission to the humerus. Therefore, an intact rotator crescent insertion plays a lesser role in this situation.

Denard et al. (2012), in a clinical study, supported the conclusion that pseudoparalysis requires the disruption of at least one of the rotator cable attachments. Postero-superior capsular damage is seen in symptomatic throwing shoulder patients as a result of impingement between the postero-superior capsulolabral part of the glenoid and the postero-superior rotator crescent and the rotator cable area (Walch et al., 1992). In the majority of these cases, which mostly impact young athletes, a significant contributing factor is the development of microinstability. It has been reported that excessive repetitive strain and damage to the superior capsule and intra-articular part of the rotator cuff tendons decrease the compressive effect of the rotator cuff and lead to GHJ instability (Economopoulos and Brockmeier, 2012). 66% to 86% of overhead athletes with articular-sided capsular or partial thickness rotator cuff tears (APTRCTs) of less than 50% of tendon thickness were treated successfully arthroscopically with debridement (Andrews et al., 1985; Payne et al., 1997; Reynolds et al., 2008).

Mihiata et al. (2015) showed in a cadaveric biomechanical study that APTRCTs did not significantly affect the stability of the GHJ compared to an intact cuff, but transtendon repair decreased subacromial and GHJ pressures at time zero and decreased the anterior translation and external rotation. Thus, it appears important to avoid the increase from a partial rotator cuff tear to a full-thickness one. The importance of the superior capsule to antero-inferior shoulder stability is reported in several cadaveric studies. Ishiara et al. (2014) reported a significant increase in GHJ translation in all directions in specimens with superior capsular defects and a significant increase in anterior translation at 30° of abduction and inferior translation at 60° of abduction. Specifically, the anterior and posterior rotator cable transection increased the anterior and inferior GHJ translation by 46.6% at 120° of external rotation and by 55.6% at 30° of external rotation (Pinkowski et al., 2017).

The presence of superior capsular tears after first-time ATSD in young athletes is not common in the literature, reportedly occurring only in 3–6% of cases (Kim et al., 2010; Shin et al., 2016).

### 2.2.2. Anterior traumatic shoulder dislocation

The shoulder is the most frequently dislocated joint in the human body, with about 8.3–12.3 cases per 100 000 (Rowe, 1956; Simonet et al., 1984; Kroner et al., 1989; Slaa et al., 2003). 90% of shoulder dislocations are anterior and traumatic and occur most frequently between 21 to 30 years of age. Conservative treatment, especially for young and active patients, leads to recurrent dislocation in about 77% to 94% (Wheeler et al., 1989; Hintermann et al., 1995; Larrain et al., 2001; Robinson et al., 2006).

The most common arthroscopic findings after first-time ATSD are an antero-inferior capsulolabral lesion with or without a bone lesion of the cavitas glenoidalis and a postero-superior ostechondral lesion on the humeral head. This has been reported in between 87–100% and 68–100% of cases (Norlin, 1993; Hintermann and Gächter, 1995; Taylor and Arciero, 1997). Rotator cuff injuries are more common in patients older than 40 years of age and have been reported in between 35% to 86% of cases (Neviaser et al., 1995; Pevny et al., 1998; Stayner et al., 2000; Hovelius et al., 2008). Comparing arthroscopic findings after first-time versus recurrent ATSD, Kim et al. (2010) and Shin et al. (2016) found a significant increase in osseus capsulolabral lesions and the presence of HSL in the recurrent group: 49.3% after first-time dislocation and 75.5% after recurrent dislocations. In patients younger than 30 years of age, rotator cuff injuries consist of mostly APTRCTs in 3 to 6% of cases and increase with recurrent dislocations to 20% (Kim et al., 2010; Shin et al., 2016).

The results of surgical treatment depend on the bone deficiency of the antero-inferior part of the glenoid and the postero-superior part of the humeral head. Burkhart and de Beer (2000) found a significant difference when comparing the recurrence rate with and without significant bone defects after arthroscopic Bankart repair. The recurrence rate was 4% without and 67% with bone defects, and for contact athletes, it was 6.5% without and 89% with bone defects.

### 2.2.3. The Hill-Sachs lesion

In 1940, Hill and Sachs first reported a compression fracture on the postero-supero-lateral part of the humeral head occurring in association with anterior dislocation of the GHJ. In the literature, this is known as the Hill-Sachs lesion (HSL) and is associated with first-time ATSD in approximately 58% to 100% of cases (Wheeler, 1989; Norlin, 1993; Hintermann and Gächter, 1995; Taylor and Arciero, 1997; Kim et al., 2010; Shin et al., 2016), as seen during arthroscopic inspection. Owens et al. (2010) reported the presence of HSL after first-time traumatic anterior subluxation events in 25 of 27 cases using MRI. In recurrent dislocation cases, the HSL had a tendency to increase both in size and depth (Cetik et al., 2007, McMahon et al., 2013). HSL is rarely an isolated injury. The most commonly associated injuries are anterior-inferior capsulolabral injures with and without glenoid bone loss.

Eichinger et al. (2016), in a cadaveric study, found a direct relationship between force and the direction of GHJ dislocation in the development of an HSL. A straight anterior GHJ joint dislocation requires more force for dislocation and has an increased risk for the development of an HSL than a combined antero-inferior dislocation.

The most useful imaging modalities to recognize an HSL are standard X-rays, Three-Dimensional Computed Tomography (3DCT) and Magnetic Resonance Imaging (MRI) (Saliken et al., 2015). X-ray imaging is useful as a screening tool for finding an HSL on the AP (anterior-posterior) view in internal rotation and on the Bernageau or West Point view (Provencher et al., 2012). 3DCT is useful for quantification and orientation of the HSL (Kodali et al., 2011; Saito et al., 2009). MRI, especially together with arthrography, may provide information about bone defects in the humeral head, along with information on associated soft tissue damage (Provencher et al., 2010). Kirkley et al. (2003) found moderate agreement between MRI and arthroscopy for the quantification of the size of the HSL. A difficulty encountered with MRI is to differentiate the HSL from the normal humeral groove, which is positioned more inferiorly and medially in the axial plane (Richards et al., 1994). There are several HSL lesion classifications systems in use (Rowe et al., 1984; Calandra et al., 1989; Richards et al., 1994; Flatow and Warner et al., 1998; Franceschi et al., 2008) based on X-ray, MRI and arthroscopic visualization. Named classifications have not yet proven to be helpful in determining successful management strategies (Provencher et al., 2012).

Humeral head lesions on the postero-superior cartilage area of >40% are responsible for recurrent instability alone, even without soft tissue injuries on the antero-inferior part of the GHJ (Flatow and Warner, 1998; Armitage et al., 2010). For HSL between 20% to 40% of the cartilage area, it is important to also consider anterior glenoid bone loss. Burkhart and de Beer (2000) describe an engaging HSL, in which the postero-superior part of the humeral head engages during abduction and external rotation. In an engaging lesion, the long-axis of the humeral head defect is oriented parallel to the anterior glenoid rim. Yamamoto et al. (2007) developed, using cadaver models, a glenoid track concept by measuring the HSL and glenoid bone-loss area in different degrees of abduction and maximum external rotation together with apprehension. The HSL has a risk to cause engagement and dislocation if it extends medially over the medial margin of the glenoid track. Provencer at al. (2010) reported a similar retionship using MRI and found this technique most relevant for classifying the HSL.

## 2.3. Surgical intervention used to treat the Hill-Sachs lesion

In the literature, different surgical techniques, such as bone augmentation, disimpaction of the lesion and partial resurfacing, are described to treat symptomatic HSL with the aim to restore the previous humeral head configuration. (Re et al., 2006; Armitage et al., 2010; Provencher et al., 2012). The most useful technique today, the remplissage procedure (in French, “to fill in”), involves a posterior capsulodesis and ISP tenodesis performed arthroscopically in patients with anterior shoulder instability and an engaging HSL. The aim of the remplissage procedure is to transform the intra-articular HSL into an extra-articular one and to prevent the humeral head from engaging with the anterior glenoid rim during abduction and external rotation of the arm. Connolly (1972) first described this technique as an open surgical procedure.

The arthroscopic technique was first described by Wolff and Pollack (2004) in combination with the Bankart repair. Koo et al. (2009) modified the technique by placing the sutures more laterally through the ISP tendon, using a double pulley suture technique with two anchors. All other further studies involving the remplissage technique concentrate on using different fixation devices and suture techniques. Tan et al. (2016) found in a biomechanical navigated robotic study that all tested techniques – using knots tied over an anchor, over double-pulley or knotless anchors with suture tape – restabilized the GHJ and sufficiently prevented engagement of the Hill-Sachs defect.

## 2.4. Summary of the literature

Being the most mobile joint in the human body, the stability of the shoulder is an intricate cooperation of static and dynamic stabilizers. Previous anatomical studies have explored the close relationship between the superior and posterior muscles and tendons of the rotator cuff and capsulo-ligamentous structures. The clinical significance of this relationship has been pointed out and explained as the suspension bridge mechanism in Burkhart´s and Halder´s works (Burkhart et al., 1993; Halder et al., 2002). The superior joint capsule and, more specifically, the rotator cable have been shown to be a crucial landmark for reconstruction after rotator cuff injury (Mochizuki et al., 2009). Meanwhile, the anatomy of this structure in the posterio-superior part of the shoulder has not been as profoundly studied.

Another aspect of the shoulder anatomy is the vascular supply of the capsulomuscular structures of the shoulder joint. The vascularity should always be taken into consideration during various surgical procedures to avoid disturbing the perfusion of the tissues. Vascularity of the postero-superior part of the GHJ and the hypovascular zone of the capsule has been reported controversially in previous studies and appears to need more research.

The role of the postero-superior joint capsule for the stability of the shoulder has been described in biomechanical studies (Ishiara et al., 2014; Pinkowski et al., 2017). In patients under 30 years of age after anterior shoulder dislocation, rotator cuff injuries are rare; if they, however, occur, they tend to be partial and intra-articular in the rotator cable or in the crescent area. There are no studies, to the knowledge of the author, on how the presence of APTRCTs influence sports activity after surgical treatment of first-time traumatic shoulder dislocation in young athletes.

During recurrent anterior shoulder dislocations, the risk of the so-called "engaging" shoulder injury increases. In addition to capsulolabral repair, the Hill-Sachs defect can be filled with the postero-superior capsule and the ISP muscle and tendon: the "remplissage" technique (Wolff and Pollack, 2004). However, even though descriptions of this technique are detailed in the literature, less is known on how to achieve a strong anatomical fixation without jeopardizing the vascular perfusion.

# 3. AIMS OF THE STUDY

**The general aim:**
To provide detailed descriptions of the structure and vascularization of the postero-superior part of the shoulder joint capsule with implementation of surgical treatment after anterior traumatic shoulder dislocation.

**Specific aims**:

1. To describe the detailed anatomy of the rotator cuff tendons in association with the rotator cable.
2. To investigate the structure and blood supply of the postero-superior joint capsule of the shoulder.
3. To identify postero-superior intra-articular traumatic rotator cuff lesions after first-time traumatic anterior shoulder dislocation and evaluate their impact on clinical results after 2 years.
4. To describe the remplissage surgical technique with respect to the anatomy of the postero-superior part of the glenohumeral joint.

# 4. MATERIALS AND METHODS

## 4.1. Materials

### 4.1.1. Specimens in Studies I, II, IV (Table 1)

Sixteen formalin–embalmed and 34 unembalmed fresh cadaveric shoulder specimens from 20 female and 30 male donors aged 52 to 82 years were used in three separate studies. All anatomic specimens were collected from voluntarily donated bodies. The studies were approved by “Gesetz über das Leichen, Bestattungs- und Friedhofweswn des Landes Schleswing-Holstein vom 04.02.2005, Abschnitt II, §9 (Leichenöffnung, anatomisch)”.

**Study I (Paper I)**
Twenty-one fresh cadaveric shoulder specimens without rotator cuff pathology with a mean age of 67.7±19.1(range, 52 to 82) years were selected for this study.

**Study II (Paper II)**
Twenty-eight cadaveric shoulder specimens, sixteen fixed and twelve fresh with a mean age of 73.4±6.4 (range, 67 to 80) years were analyzed.

**Study IV (Paper IV)**
For the anatomic illustration of the surgical technique, one fresh cadaveric shoulder specimen from a female donor, 76 years of age, was used.

**Table 1.** Cadaveric shoulders and methods used in I, II and IV studies

| Study | Gender | Shoulder condition | Methods |
|---|---|---|---|
| **I** | 9F/12M | 21 UE | Anatomical dissection |
| **II** | 10F/18M | 12 UE<br>16 E | Anatomical dissection with arterial injection<br>Anatomical dissection |
| **IV** | 1F | 1UE | Anatomical dissection with arterial injection |

F – female, M – male, UE – fresh unembalmed, E – formalin embalmed

### 4.1.2. Patients in Studies III and IV

Seventeen male patients aged 17–26 years were included in studies III and IV. The studies were approved by the Tallinn Medical Research Ethics Committee (decision no. 2952).

**Study III (Paper III)**
Sixteen male patients with a mean age of 21.0±2.6 (range, 16 to 25) years with first-time ATSD without anterior glenoid rim fracture were included in the study.

The indications for surgical treatment were an age of <25 years and being active in collision or contact sports on a competitive level (Table 2).

**Study IV (Paper IV)**

One male patient 26 years old with an HSL and a concomitant rotator cable tear of the posterior part, but without anterior glenoid bone loss, was selected for describing the anatomic remplissage technique.

**Table 2.** Characteristics of male patients included in Study III

| Patient No | Age (years) | Side | Arm dominance | Spots activity | Time between injury and surgery (days) |
|---|---|---|---|---|---|
| 1 | 25 | Left | ND | Ice hockey | 9 |
| 2 | 24 | Right | D | Wrestling | 2 |
| 3 | 23 | Right | D | Motocross | 9 |
| 4 | 17 | Right | D | Judo | 7 |
| 5 | 21 | Right | D | Soccer | 8 |
| 6 | 18 | Right | D | Judo | 3 |
| 7 | 25 | Left | ND | Motocross | 8 |
| 8 | 19 | Left | ND | Judo | 4 |
| 9 | 19 | Left | ND | Volleyball | 8 |
| 10 | 19 | Right | D | Motocross | 11 |
| 11 | 21 | Left | ND | Ice hockey | 9 |
| 12 | 20 | Right | ND | Handball | 7 |
| 13 | 21 | Right | D | Soccer | 8 |
| 14 | 20 | Right | D | Wrestling | 10 |
| 15 | 24 | Right | ND | Bicycle motocross | 9 |
| 16 | 18 | Right | D | Handball | 12 days |

D – dominant, ND – non-dominant

## 4.2. Methods

### 4.2.1. Cadaveric studies

With the exception of the rotator cuff muscles and biceps brachii (long head of the biceps) muscle tendon, all muscles of the shoulder girdle were removed during the anatomic dissections. The acromion was separated from the spina scapulae and elevated with the coracoacromial ligament. Remnants of the subacromial bursa and loose connective tissue were removed from the rotator cuff muscles and tendons.

In Study I, the rotator cuff muscles were dissected from each other and from the GHJ capsule. The superior glenohumeral, coracohumeral, coracoglenoidal and semicircular ligaments were dissected. Dissection was performed layer by layer and from the bursal side towards the joint. All ligaments and tendons were dissected in fine detail. The bony insertion areas of the rotator cuff tendon were left intact. Finally, posterior capsulotomy was performed to allow visualization of the intra-articular side of the rotator cable insertion area. Gross evaluation of the ligaments and fibrous structure of the tendons was independently performed by two anatomists and two shoulder surgeons. In questionable cases, a consensus among all four examiners was reached by discussion. Special emphasis was placed on the presence of a rotator cable and overlap of the ISP and SSP tendons.

In Study II and IV, before dissection, an arterial injection of a 10% aqueous latex solution (stabilized with ammonia) was administered. Each specimen was simultaneously injected with 200 ml of latex solution via both the subclavian and brachial arteries. After the injection, the shoulders were fixed in an alcohol–formalin–glycerol solution and meticulously dissected under a dissection microscope.

The SSP, ISP and teres minor (TM) tendons and muscles were exposed posteriorly and the pectoralis minor anteriorly by removing any superficial muscles and tissues to expose the blood vessels. The tendon of the pectoralis minor muscle was carefully reflected laterally, thus revealing the neurovascular structures of the axillary sheath. The veins, nerves and remaining axillary fat were removed to provide clear visibility of the subclavian and axillary arteries and their branches, as well as the subscapularis muscle and tendon.

The arteries were followed to the coracohumeral ligament and then to the surface of the rotator cuff muscles and their tendons. Each of the rotator cuff muscles was reflected laterally, with care taken not to disrupt the vessels coursing towards the joint capsule. The course of each blood vessel was documented with photographs throughout the dissection process.

### 4.2.2. Clinical Studies

In Study III, the arthroscopic operation was performed by one experienced surgeon. The GHJ visualization was executed, and images were captured during the procedure. During arthroscopic inspection through the posterior portal, the anterio-inferior capsulolabral injuries, anterior glenoid, rotator interval area, biceps longus tendon's stability and attachment, subscapularis tendon, superior capsulomuscular, and glenohumeral cartilage area were all visualized, inspected and palpated with a probe from the anterior portal. Antero-inferior capsulolabral injuries were recorded using a clock-face system. The HSL were visualized and checked during arm abduction and external rotation for engaging with the antero-inferior glenoid. Evaluation and description of the damaged structures were independently performed by two experienced shoulder surgeons. Differences in opinion between the two surgeons were resolved by discussion with the clinical anatomy specialists.

Classification of the articular-side partial-thickness rotator cuff tears (APTRCTs) was done during arthroscopy using the Southern California Orthopedic Institute (SCOI) rotator cuff classification (Snyder, 2003):
Grade 0: Normal cuff
Grade 1: Slight capsular fraying in a small, localized area; usually <1 cm in size
Grade 2: Fraying or failure of some rotator cuff fiber in addition to capsular injury; usually <2 cm in size
Grade 3: Fraying and fragmentation of tendon fibers, often involving the whole surface of a cuff (supraspinatus) tendon; usually <3 cm in size
Grade 4: In addition to fraying and fragmentation of the tendon, the presence of a sizable flap tear which often encompasses more than one tendon

HSL classification was done during arthroscopy using the Calandra (Calandra et al., 1989) classification system:
Grade 0: No lesion
Grade 1: Defect of the articular surface not involving the subchondral bone
Grade 2: Small defect involving the subchondral bone, ≤1 cm
Grade 3: Large defect involving the subchondral bone, >1 cm

Clinical evaluation: An independent physiotherapist not involved in the rehabilitation of the patients performed the clinical evaluations at a minimum of two years after surgery using the ASES (American Shoulder and Elbow Surgeons) score (Richards et al., 1994), Rowe score (Rowe et al. 1978), and measurements of range of motion (ROM). Measurement of ROM was performed using a goniometer and was compared with the contralateral healthy shoulder (Figure 1).

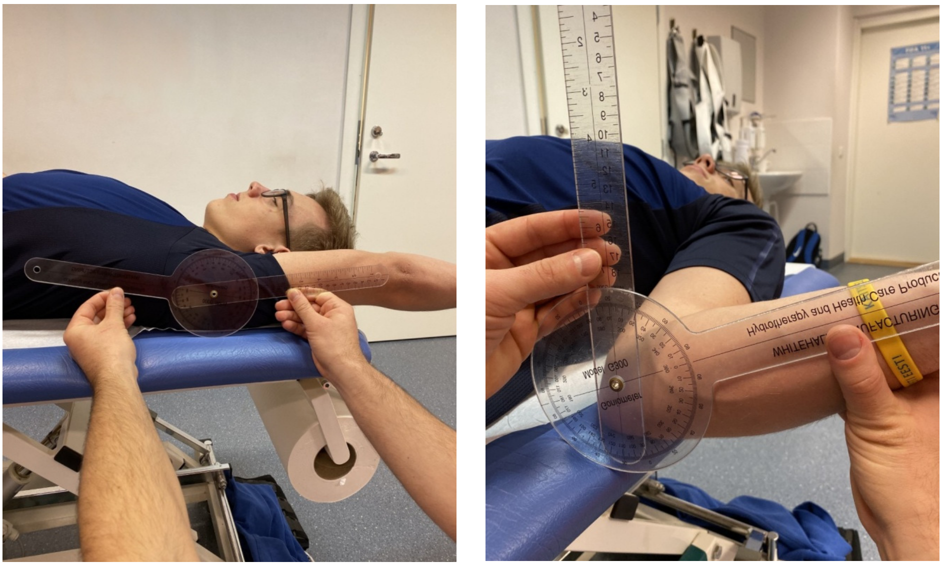


**Figure 1.** The measurement of range of motion using a goniometer.

Specific tests: The apprehension test was used as a specific test for grading recurrent instability and was classified dichotomously as positive or negative depending on whether there was a protecting muscular contraction or not during the test.

Rehabilitation: Postoperative rehabilitation was performed by the same physiotherapist using the same guidelines for all patients: immobilisation for 4 weeks (Figure 2), pendulum exercises from 4 weeks and full ROM from 12 weeks. Full return to sports was permitted, at the earliest, at 16 weeks after surgery.

**Figure 2**. Immobilisation of the shoulder after operation.

In Study IV, the remplissage procedure was performed arthroscopically, using two posterior working portals in the beach chair patient position. The posterior portal was placed in the soft spot 2 to 3 cm inferior and 2 to 3 cm medial to the postero-lateral corner of the acromion. Additionally to the postero-lateral portal, a posterior portal was placed about 2 to 3 cm lateral to the first portal at the same horizontal level (Figure 3).

**Figure 3.** The remplissage procedure using two posterior portals: the camera is positioned in the standard posterior portal; a yellow needle marks the position of the postero-lateral portal (Paper IV).

The sutures for the remplissage procedure were positioned in the horizontal plane parallel to the ISP fibers, from lateral to medial, to avoid disturbance of the vascularization of the infraspinatus tendon and posterior capsule in line with what was previously tested in cadavers (Figures 4, 5).

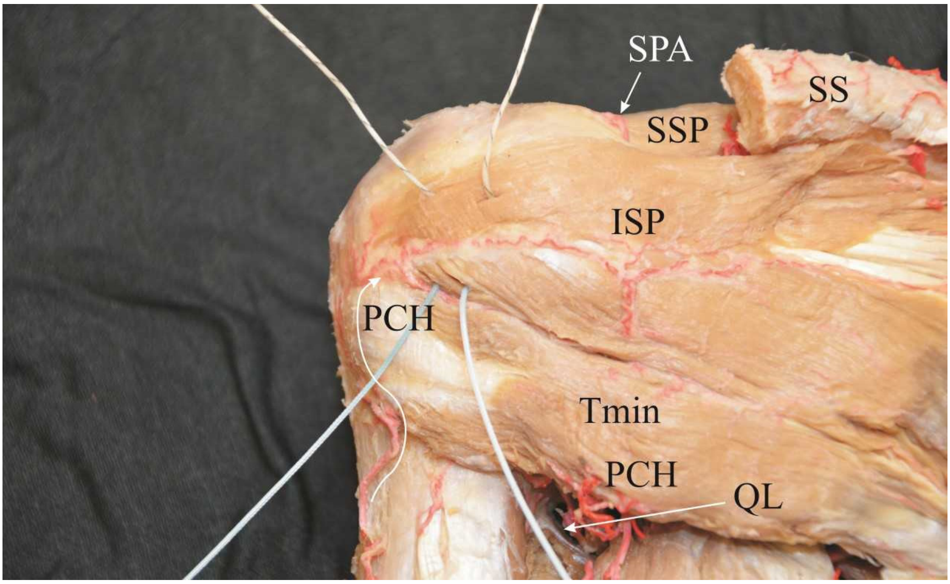


**Figure 4.** Cadaver illustration of the positioning of the remplissage sutures in the subacromial space after the removal of the acromion and subacromial bursa (Paper IV). The superior suture is white with a black stripe, and the inferior suture is blue. Other structures include: infraspinatus muscle (ISP); posterior humeral circumflex artery (PCH); quadrilateral space (QL); suprascapular artery (SPA); spina scapulae (SS); supraspinatus muscle (SSP) and teres minor muscle (Tmin).

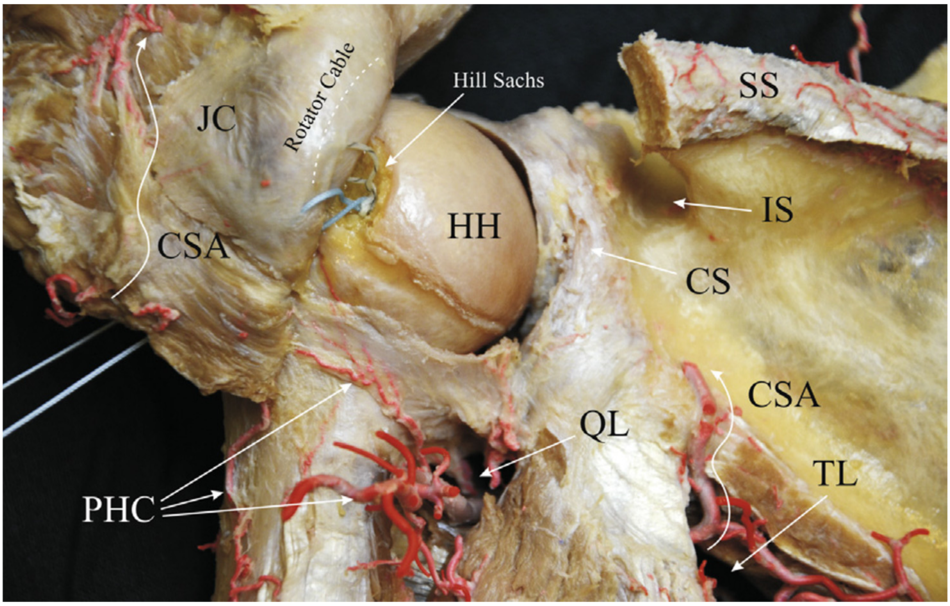


**Figure 5.** Cadaveric illustration of a left shoulder showing the position of the remplissage sutures inside the joint (Paper IV). The superior suture is white with a black stripe, and the inferior suture is blue. Other structures include: collum scapulae (CS), circumflex scapular artery (CSA), humeral head (HH), incisura scapulae (IS); joint capsule (JC), posterior humeral circumflex artery (PHC), quadrilateral space (QL), spina scapulae (SS) and trilateral space (TL).

## 4.3. Statistical methods

The age was reported as mean (range; SD) (Paper I, II, III).

In Paper III, the Mann-Whitney U test was used for the comparison of the ASES and Row scores between the patients with and without APTRCTs. Categorical variables were compared using the chi-square test. A P value <.05 was considered significant. The primary variable of the study was the presence of rotator cuff injuries in young athletes. A post-hoc power analysis revealed that if 56% (9/16) of patients have this type of injury instead of no patients at all, approximately 18 patients would be required to reach a power of 80%.

# 5. RESULTS

## 5.1. Anatomy of the rotator cuff tendons in association with the rotator cable (Paper I)

The rotator cable was identified in all 21 shoulder joint specimens as an organized, parallel-running bundle of connective tissue fibres forming a curved capsular-ligamentous structure in the supero-lateral part of the GHJ capsule (Figure 6).

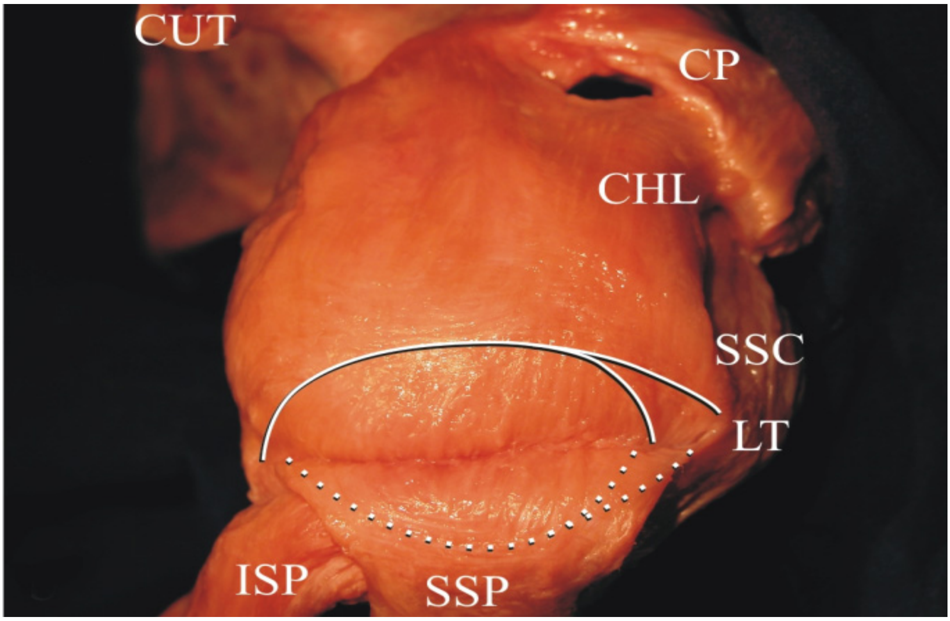


**Figure 6**. Supero-lateral view of the right glenohumeral joint capsule. Rotator cuff tendons are sharply dissected off the joint capsule and the rotator cable (*white line*), and the track of capsular insertion area of the SSP muscle tendon (dotted line) can be seen following the course of the semicircular ligament. The infraspinatus (ISP) muscle tendon is overlapped by the supraspinatus (SSP) muscle tendon on articular side. Other structures include the coracohumeral ligament (CHL), coracoid process (CP), cut acromion base (CUT), *LT* lesser tubercle (LT) and subscapularis (SSC).

The posterior insertion of the ligament was located in the area between the middle and inferior facets of the greater tubercle of the humerus, between the insertion areas of the TM, SSP and ISP tendons (Figure 7A).

On the articular side, the insertion area of the rotator cable was lateral to and near the cranial apex of a triangular-shaped area of bare bone between the articular cartilage and the capsular insertion area (Figure 7B).

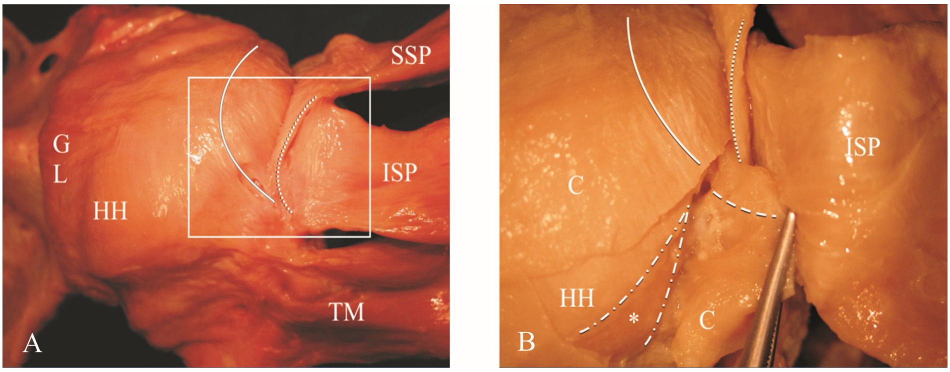


**Figure 7.**
**A:** Posterior view of the right glenohumeral joint capsule with the acromion cut and removed and the supraspinatus (SSP), infraspinatus (ISP) and teres minor (TM) muscles retracted laterally. The posterior insertion area of the semicircular humeral ligament (SCL) (*white line*) is seen between the ISP and TM muscles tendons. Visible are the overlapping SSP and ISP tendons and the insertion of the posterior edge of the SSP (*dotted line*) with SCL under the ISP. The *white square* marks the area that is magnified in figure 7B.
**B:** Detailed view of the SCL (*white line*) posterior insertion area. The joint capsule (C) is cut and lifted laterally with forceps, the intra-articular side of the SCL (*dashed line*) can be seen, with the SCL inserting laterally and near the cranial corner of the area of bare bone (*asterisk*). Borders are marked with a *dashed-dotted* line. Other structures include the joint capsule (C), glenoid labrum (GL) and humeral head (HH).

The deep fibres of SSP, which inserted into the joint capsule at the level of the capsular semicircular ligament, were found in all specimens. The deep fibres were interwoven with the ligament and attached to the bone through the ligament (Figure 7A, white dotted line).

## 5.2. The structure of the glenocapsular ligament and blood supply of the postero-superior part of the shoulder joint capsule (Paper II)

The posterior and postero-superior parts of the joint capsule and the glenocapsular ligament were vascularized from the posterior ascending branch of the circumflex artery. These small branches were located parallel with the connective tissue fibres of the glenocapsular ligament (Figure 8).

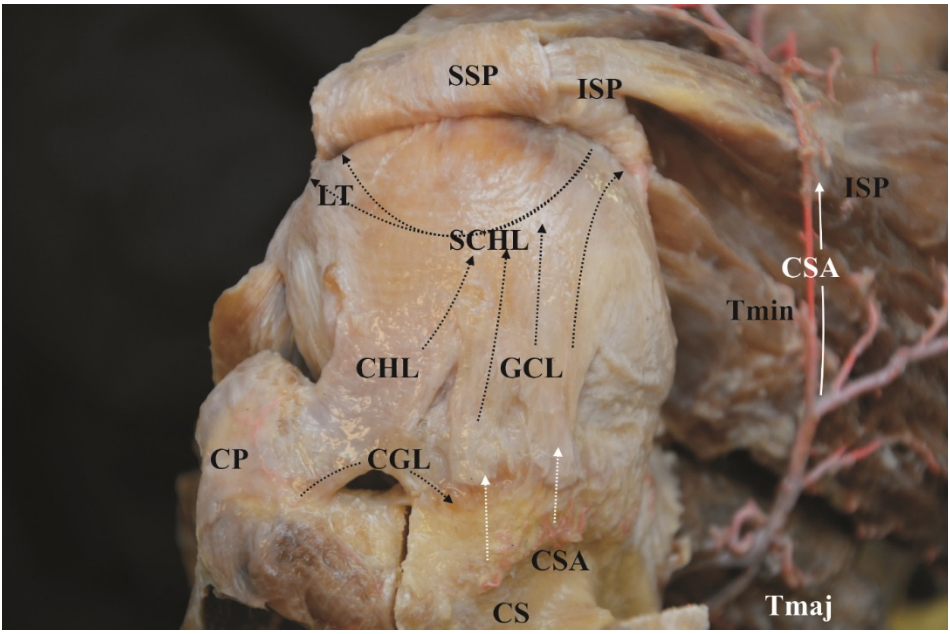


**Figure 8.** Superior view of a dissected specimen of the right glenohumeral joint with blood vessels.The posterior circumflex scapular artery (CSA) was cut from the small branches (white paired arrows) and placed laterally from the joint capsule (white upward arrow). These small branches supply blood to the mediosuperior (black upward bold arrow) and posterosuperior (black upward paired arrows) parts of the glenocapsular ligament (GCL). Other structures include the supraspinatus (SSP), infraspinatus (ISP), subscapular(SSC), teres minor (Tmin), teres major (Tmaj), coracoglenoidal ligament (CGL), coracoid process (CP), coracohumeral ligament (CHL), semicircular humeral ligament (SCHL) and lesser tubercle (LT).

The posterior descending branches of the circumflex scapular artery supplied the ISP, teres major and minor muscle bellies on the articular side. The posterior ascending branch supplied the SSP muscle belly from below. The suprascapular artery supplied the ISP tendon on the articular side (Figure 9).

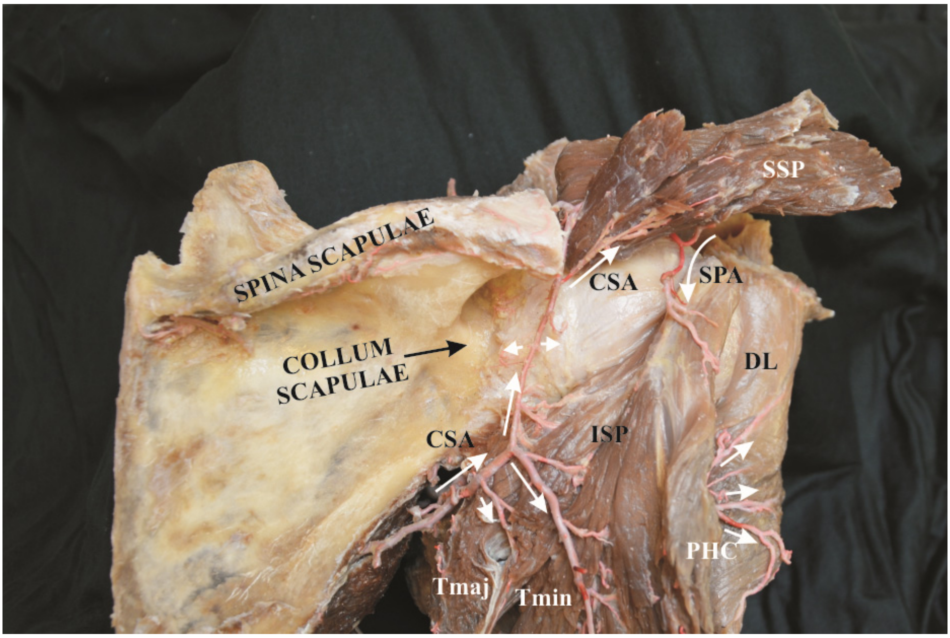


**Figure 9.** Posterior view of a dissected specimen of the right humeral joint with its arteries.The circumflex scapular artery (CSA) splits near the inferior part of the collum scapulae into posterior ascending (white upward arrow) and descending (white downward arrow) branches. The posterior ascending branch supplies blood to the supraspinatus (SSP) muscle belly from below. Prior to reaching the SSP, small branches (two small white arrow horizontally) run laterally and medially from the CSA to supply the posterior and postero-superior parts of the joint capsule. The posterior descending branches (white downward paired arrow) supply the infraspinatus (ISP), and teres major (Tmaj) and minor (Tmin) muscles bellies. The suprascapular artery (SPA) supplies the infraspinatus tendon on the articular-side. The posterior circumflex humeral artery (PHC) supplies blood (three white arrows) to the deltoid muscle (DL).

The glenocapsular ligament (GCL), which arose from the supraglenoid tubercle and collum scapulae and inserted into the semicircular humeral ligament of the postero-superior shoulder joint capsule, was found in all 28 specimens. It consisted of one and two parallel-running bundles of connective tissue fibres. The postero-superior part was found in all cases at the gap between the SSP and ISP muscles on a line extending from the spina scapulae (Figure 10). The medio-superior part varied in shape and was found in 12 of 28 cases.

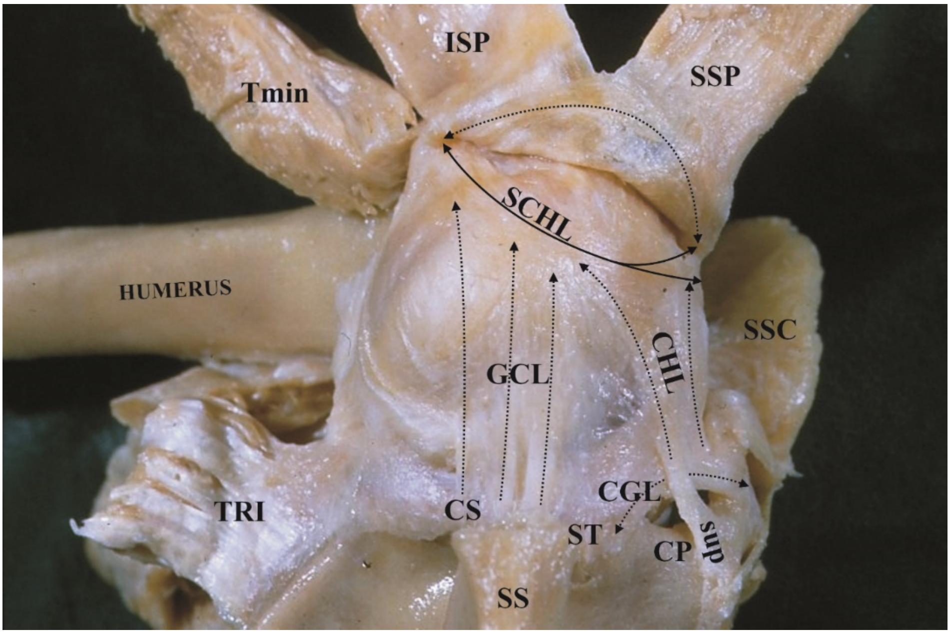


**Figure 10.** Postero-superior view of a dissected specimen of the left glenohumeral joint. The glenocapsular ligament (GCL) with its two parts – the posterosuperior part (*black upward paired arrow)* and the mediosuperior part (*one black upward arrow*) – arising from the collum scapulae (CS) and supraglenoid tubercle (ST), and inserting into the semicircular humeral ligament (SCHL); one part of the semicircular humeral ligament (*mirror arrow*) is indicated on the under surface of the supraspinatus (SSP) and infraspinatus (ISP) tendons. Other structures displayed are the separate superior (sup) part of the coracohumeral ligament (CHL), coracoglenoidal ligament (CGL), coracoid process (CP), subscapularis muscle (SSC), teres minor muscle (Tmin), triceps brachii muscle (TRI) and spina scapulae (SS).

## 5.3. Intra-articular rotator cuff lesions after first-time traumatic anterior shoulder dislocation in young male athletes: outcomes of surgical treatment (Paper III)

An antero-inferior capsulolabral lesion was found in all patients. HSL were found in 14 patients at surgery. Seven lesions were grade 1, and 7 were grade 2. An additional superior labral anterior posterior (SLAP) type 5 lesion was found in 1 patient and an isolated chondral lesion of the humeral head in another patient.

Nine of the 16 patients had APTRCTs in the superior part of the shoulder joint involving the rotator cable. The rotator cable was divided into 3 zones: the anterior and posterior rotator cable attachment areas and the middle rotator crescent area (Figure 11).

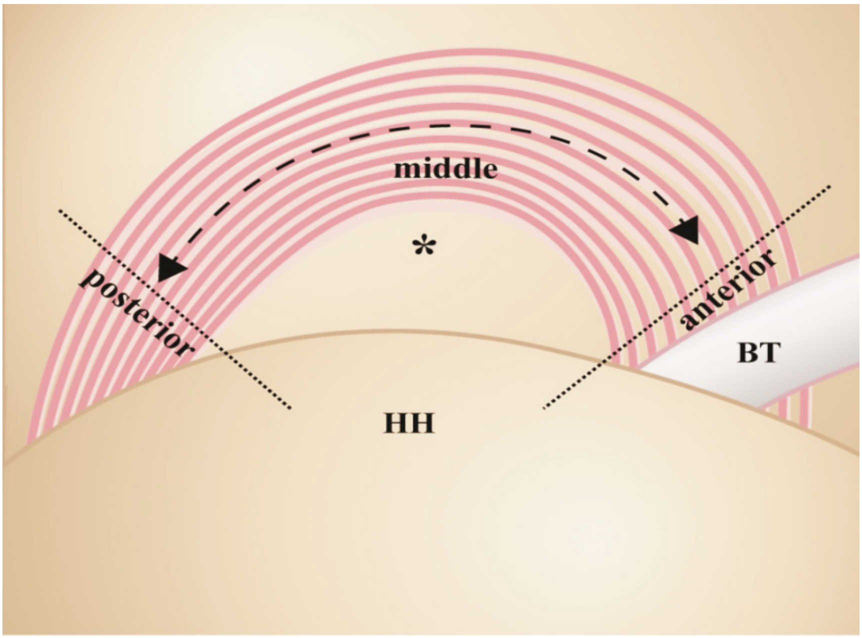
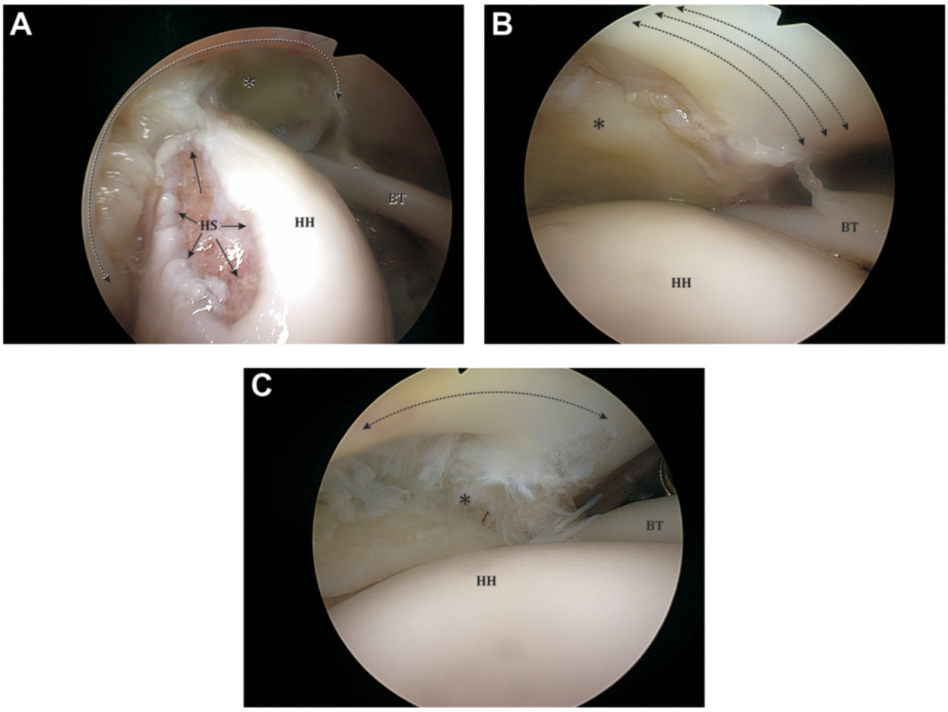


**Figure 11.** The schematic drawing of three zones of the superior intra-articular capsulo-muscular area. *Anterior* anterior rotator cable attachment area; *middle* middle part of rotator cable with rotator crescent; *posterior* posterior rotator cable attachment area; *HH* humeral head; *BT* long head of biceps tendon; <---------> rotator cable; * rotator crescent.

The anterior insertion area of the rotator cable was affected in 2 patients, the rotator crescent area in 5 patients, the posterior insertion area in 6 patients (Figures 12 A, B, C). An isolated injury of the posterior insertion of the rotator cable was identified in 4 patients.



**Figures 12**. Arthroscopic view of the left shoulder through the posterior portal showing a Hill-Sachs lesion, rotator crescent injuries, and anterior part of the rotator cable injuries (Paper II): (A) Hill-Sachs lesion (grade 2) and rotator crescent injury (A2), (B) rotator crescent and anterior part of the rotator cable injuries, and (C) rotator crescent and anterior part of the rotator cable injuries after debridement. *BT* long head of the biceps tendon; *HH* humeral head; *HS* Hill-Sachs lesion; <---------> rotator cable; * rotator crescent.

A follow-up was performed at a mean of 32 months (range, 24–38 months) after surgery. 13 of 16 patients had returned to their pre-injury level of activity at follow-up, and the remaining 3 patients had returned to sports activities at a lower level. There were no significant differences in ASES or Rowe scores between the study groups at follow-up. Patients who had APTRCTs had a tendency toward greater loss of ROM in abduction/external rotation than patients without APTRCTs (*p value* .05) (Table 3). Based on the patients' reports and medical history, no recurrences of frank dislocation and/or subluxation episodes were registered during the follow-up period.

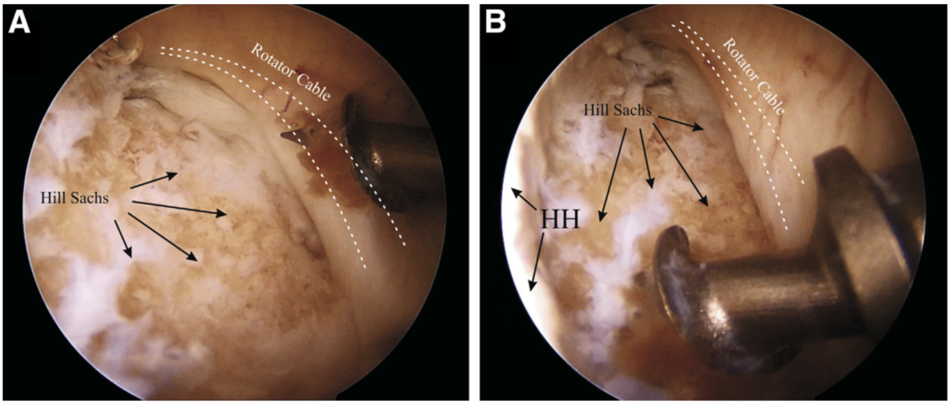
**Table 3.** Comparison of clinical outcomes in male patients with APTRCT versus those without at a minimum of 2 years after surgery

| Variable | APTRCT | No APTRCT | p-value |
|---|---|---|---|
| **No. of patients** | 9 | 7 | |
| **Age (years)** | 19.8 (17–25) | 21 (18–25) | .75 |
| **Arm(dominant/non-dominant)** | 4/5 | 5/2 | .52 |
| **ROWE score (points)** | 90 (55–100) | 87.1 (50–100) | .69 |
| Excellent (90–100) | 7 | 5 | |
| Good (70–89) | 1 | 1 | |
| Fair (40–69) | 1 | 1 | |
| Poor (less than 40) | 0 | 0 | |
| **ASES (points)** | 94.6 (81–100) | 90.4 (76–100) | .67 |
| **Return to same level sport** | 8 | 5 | .37 |
| **Recurrence of dislocation** | none | none | |
| **ROM limitation no/yes** | 4/5 | 4/3 | .61 |
| **Loss of ROM compared with contralateral side (degrees)** | | | |
| External Rotation | 8.3 | 4.3 | .56 |
| Internal Rotation | 0 | 0 | >.99 |
| Elevation | 0 | 0 | >.99 |
| Abduction/internal rotation | 1.7 | 0 | .10 |
| Abduction/external rotation | 2.8 | 0 | .05 |

Values shown as mean (range)
APTRCT: articular-side partial-thickness rotator cuff tear
ASES: American Shoulder and Elbow Surgeons

## 5.4. The remplissage procedure based on the postero-superior capsulomuscular anatomy and vascularity (Paper IV)

Debridement of the Hill-Sachs lesion area is performed with a shaver. A 5.5-mm titanium anchor with 2 or 3 cords is inserted close to the medial border of the humeral head defect, approximately 1 cm inferior to the superior border and in line with the rotator cable insertion area (Figures 13 A and B).



**Figures 13**. Arthroscopic view of the right shoulder through the posterior portal showing a Hill-Sachs lesion after debridement (A) and insertion of a titanium anchor through the additional posterolateral portal to the humeral head defect area (B). *HH* humeral head.

The sutures are positioned in the horizontal plane, parallel to the ISP fibers. Initially, the superior suture is placed over the posterior part of the rotator cable, using a sharp penetrator (Figure 14).

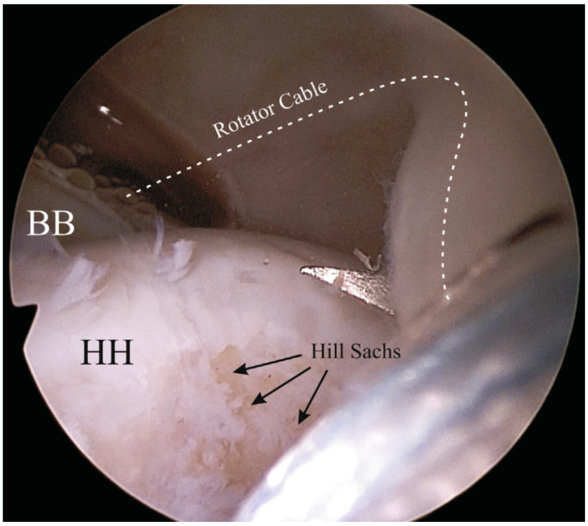


**Figure 14.** Arthroscopic view of the right shoulder through the posterior portal showing the use of the penetrator instrument to attach the posterior part of the rotator cable to create a superior suture through the additional posterolateral portal. *BB* long head of biceps tendon; *HH* humeral head.

Subsequently, a second suture is placed in the same way, just inferior to the first suture. The direction of the sutures must be from lateral to medial to preserve the vascularization of the infraspinatus tendon and the capsule (Figure 15 A and B).

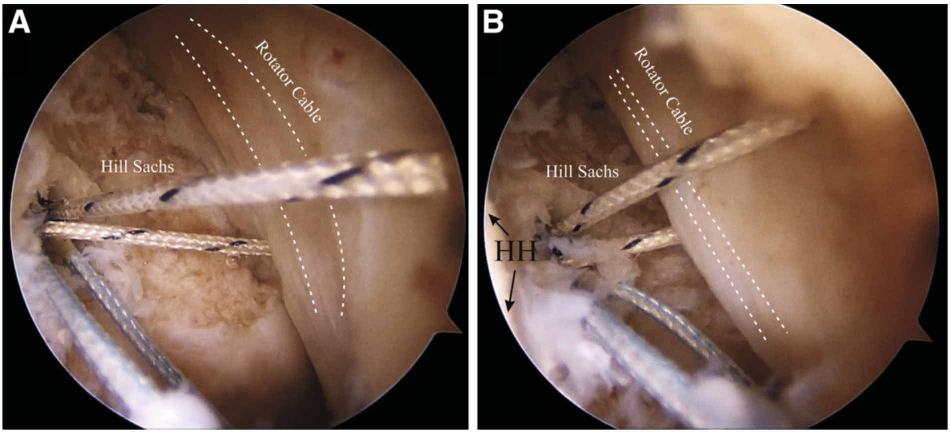


**Figure 15.** Arthroscopic view of the right shoulder through the posterior portal showing suture positions after attaching the rotator cable during the remplissage procedure. *HH* humeral head.

All steps of the arthroscopic remplissage procedure technique with commens are visible in added video with Paper IV.

# 6. DISCUSSION

The most important aspects of this thesis are the detailed descriptions of the postero-superior capsulo-ligamentous structures, including the blood supply of the GHJ. Other notable aspects include the description of the importance of these structures for the surgical outcome of patients with first-time ATSD and for the surgical performance of the remplissage procedure.

## 6.1. The postero-superior part of the joint capsule: anatomic considerations

The most important findings of the thesis are that the SSP tendon is tightly connected all the way to the rotator cable and that the posterior insertion area of the rotator cable is complex, involving insertion fibres from the SSP, ISP and TM tendons. Another important finding is the existence of the GCL in the posterior-superior part of the shoulder joint as a connecting structure in the capsule between the posterior part of the rotator cable, with the supraglenoid tubercle and the collum scapulae, and the gap between the SSP and ISP muscles on a line extending from the spina scapulae.

With regard to its posterior insertion, Burkhart et al. (1993) described the rotator cable as extending to the inferior edge of the ISP tendon. Kolts et al. (2000) described this structure as a capsular ligament and named it semicircular humeral ligament. Study I found that the deep fibres of the SSP tendon inserted into the rotator cable and reached through that structure to the posterior aspect of the humeral head. Moreover, it found that the rotator cable is a capsular insertion area for the SSP tendon and that the superior fibres of the TM muscle tendon also insert near the same area.

The intra-articular bony landmark for the posterior insertion area of the rotator cable is supposed to be on the lateral and cranial edge of the posterior bare bone area. Unfortunately, this location is not very reliable because the area of bare bone may vary between individuals and with age (de Palma et al. 1949).

In addition to their description of the rotator cable, Burkhart et al. (1993) proposed the “suspension bridge“ theory for rotator cuff tears. This theory was later confirmed by a biomechanical study by Halder et al. (2002). Study I also demonstrated the connection between the SSP tendon and the rotator cable and supports the “suspension bridge” theory.

The GCL was first described in conference thesis by Kolts et al. (2000) as a connecting ligamentous structure between the rotator cable and the cavitas glenoidalis. Poliart et al. in 2007 found this ligament in 89.6% of specimens and noted that the importance of this ligament, together with the coracoglenohumeral ligament, is to anchor the rotator cable medially to the cavitas and to help to depress and centralize the humeral head and support the rotator cable function. In Study II, it was found that two different parts of the GCL exist; the postero-superior and the medio-superior part. The postero-superior part was found in all specimens, while the medio-superior was found in 12 of 28 cases.

The importance of the rotator cable for GHJ stability was reported in a cadaveric study. Ishihara et al. (2014) showed that the integrity of the superior capsule significantly affects the anterior and inferior translation of the GHJ. Pinkowski et al. (2017) showed in another cadaveric study that the rotator cable is important for glenohumeral antero-inferior stability.

The findings of Study I further stress the importance of the rotator cable in instability cases in which the rotator cable is involved in maintaining a seamless shoulder function.

According to the current anatomic findings, it is possible to conclude that most partial intra-articular rotator cuff tears can be considered SSP tears, and the postero-superior part of the GCL is a connecting structure between the SSP and ISP muscle parts in the joint capsule area, medially supporting the capsular part of the rotator cable. In these cases, the rotator cable and GCL might be useful landmarks for anatomic restoration of the musculocapsular integrity of the GHJ.

## 6.2. The postero-superior part of glenohumeral joint capsule with emphasis on blood supply

For the blood supply of the whole GHJ capsule, the suprascapular, circumflex scapular and posterior circumflex humeral arteries are responsible (Cooper et al., 1992). Chansky et al. (1991) found that the posterior circumflex humeral artery was responsible for posterior rotator cuff vascularization. Põldoja et al. (2017) found that the posterior circumflex humeral artery is additionally responsible for the blood supply of the posterior part of the bursa.

Andray et al. (2002) suggested in a schematic illustration that the posterior part of the joint capsule is mostly supplied via the circumflex scapular and suprascapular arteries. In Study II, the underlying deep layer of the joint capsule and the glenocapsular ligament itself were supplied with blood by the ascending branch of the circumflex scapular artery, which arises vertically in relation to the scapular neck and feeds small branches horizontally to the glenocapsular ligament. The posterior descending branches of the circumflex scapular artery supplied the ISP and TM muscle bellies on the articular side.

In Study II, it was found that the suprascapular artery supplied the ISP tendon on the articular side. This finding is clinically relevant because preserving vascularity while suturing the ISP and during the remplissage procedure is important to avoid future degenerative processes and ruptures of the ISP (Löhr et al., 2007).

## 6.3. Clinical implication of the postero-superior part of the joint capsule after anterior traumatic shoulder dislocation

In Study III, the presence of articular-sided rotator cuff injuries was found in the superior part of the GHJ in more than half of the young male athletes when evaluating the superior capsule.

In previous studies, the presence of APTRCTs has not been a common finding after first-time traumatic anterior dislocation in young patients. Shin et al. (2016) reported that only 1 of 33 patients under the age of 30 years had an APTRCTs at surgery after an acute shoulder dislocation. Kim et al. (2010) found that 2 of 33 patients aged between 17 and 33 years had an APTRCTs involving less than 25% of the rotator cuff.

Superficial intra-articular rotator cuff tears with capsulolabral fraying are symptomatic in 93% of overhead athletes by causing posterior internal impingement (Paley et al., 2000). Based on patient reports and medical history all patients in the Study III were asymptomatic before injury. Furthermore, the lesions found at surgery appeared acute, with hematomas or bleeding, and could therefore be distinguished from older overuse injuries. It therefore appears unlikely that the lesions found resulted from internal impingement. Strauss et al. (2011) in a systematic review reported that APTRCTs of less than 50% thickness may be treated successfully with debridement, which is in line with the approach in Study III.

Shin et al. (2016) compared accompanying injuries and clinical results between primary and recurrent dislocation patients. In recurrent dislocation patients, they found significantly more bony Bankart type lesions, Hill Sachs lesions and partial thickness rotator cuff damages. In clinical results, they did not find any statistical differencies in ASES and ROWE scores, but the number of patients with recurrence of instability was significantly higher in recurence group (1/16, *p value* .039). Based on this study, they recommend to operate on patients younger than 30 years old after first- time shoulder anterior dislocation. In the present study, ASES and ROWE scores were similar to those in other studies and no significant differences were found in the ASES score, Rowe score, or ROM in most dimensions between patients with versus without APTRCTs. Based on the patients' reports and medical history, no recurrences of frank dislocation and subluxation episodes were registered during the follow-up period.

## 6.4. Remplissage operation technique

The previously described remplissage techniques (Wolf et al., 2004; Koo et al., 2009; Alexander et al., 2016; Tan et al., 2016) focus on achieving a strong fixation of the posterior capsule together with the ISP tendon using a less invasive procedure to avoid engagement of the humeral head with the anterior glenoid rim during abduction and external rotation. The technique in Paper IV is based on the anatomical structure of the postero-superior part of GHJ, attaching the capsule, the ISP tendon and the posterior part of the rotator cable together into the Hill-Sachs defect while respecting the vascular anatomy.

Based on the findings of Ishiara et al. (2014) and Pinkowski et al. (2017) on the importance of the superior capsule and rotator cable integrity for the antero-inferior stability of the GHJ, the remplissage technique was also used for posterior rotator cable attachment lesions without engaging HSL in Study IV.

## 6.5. Scientific novelty and clinical relevance

It appears that the rotator cable, especially its posterior insertion area, is an important part of the postero-superior GHJ. It serves as a connecting structure between the SSP, ISP and TM tendons, and it can be affected during shoulder dislocation.

This was confirmed in Study III, in which APTRCTs were found in more than 50% of patients after anterior shoulder dislocation. Grade 1 and 2 APTRCTs were treated with debridement, which rendered similar results compared to patients without APTRCTs after 2 years. To the knowledge of the author, this is the first study in which the clinical results of the treatment of such an injury have been reported.

Based on the novel findings in Study II, in terms of the vascularity of the postero-superior capsule via the circumflex scapular artery, a new arthroscopic remplissage technique was developed. In this technique, horizontal sutures placed more laterally preserve the vascularity of the ISP and postero-superior capsule during the remplissage procedure.

## 6.6. Future perspectives

1. It appears important to examine the value of using the remplissage technique from Study IV not just for engaging lesions, but also for lesions of the posterior part of the rotator cable in patients with post-traumatic shoulder instability.
2. To use the glenocapsular ligament as a posterior landmark when restoring the superior capsule in patients with irreparable SSP tears appears to be valuable for shoulder surgeons. To evaluate the actual blood flow in live patients in the posterior structures of the shoulder after using the remplissage technique in Study IV appears important.

## 6.7. Limiting factors

In the cadaveric studies, the specimens were from donors who were rather old. Therefore, application of the results of this thesis to younger populations may be limited. Another limitation is the lack of measurements of the structures. During the dissection, parts of the structures were sacrificed to better visualize the fibrous structures. Consequently, some anatomic structures could not be measured. However, these measurements have been performed and described in previous studies.

The limitations of study III were the small number of patients and the lack of a control group. The small number of patients did not provide adequate power for a proper analysis, and a control groups with either no treatment or repair of the APTRCTs would have substantially increased the impact of the study.

# 7. CONCLUSIONS

1. The posterior rotator cable insertion area is a connecting structure between the SSP, ISP and TM tendons. The connection between the rotator cable and rotator cuff tendons is tight and confirms the suspension bridge theory for rotator cuff tears in most areas between the SSP tendons and rotator cable.
2. The postero-superior part of the joint capsule appears to be well vascularized via the posterior ascending branch of the circumflex scapular artery. The glenocapsular ligament is a constant anatomical structure and consists of one or two different parts.
3. APTRCTs were found in the superior part of the shoulder joint after a first-time traumatic anterior shoulder dislocation in young male athletes. All of them were less than 50% thickness and were treated successfully with debridement. At 2 years after surgical treatment of a first-time anterior shoulder dislocation, there were no significant differences found between the patients with and without APTRCTs in terms of the Rowe and ASES scores.
4. The remplissage technique in which the sutures are inserted from lateral to medial, attaching the rotator cable in the horizontal plane, allows for stronger fixation and avoids damage to the blood supply of the posterior capsule and ISP tendon.

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# 10. SUMMARY IN ESTONIAN

## Õlaliigese kapsli tagumis-ülemise piirkonna struktuuri ja verevarustuse uurimistulemuste rakendamine õlaliigese eesmise traumaatilise nihestuse kirurgilises ravis

### Sissejuhatus

Õlaliigese eesmise nihestuse korral liigub õlavarreluu-pea üle abaluu liigeseõõnsuse eesmis-alumise serva ja haakub selle serva taga õlavarreluu-pea tagumis-ülemise pinnaga. Selle nihestusega kaasnevad sageli abaluu liigeseõõnsuse eesmis-alumise osa luulised või/ja kapsulolabraalsed vigastused ja õlavarreluu-pea tagumis-ülemise osa kahjustus, mida nimetatakse Hill-Sachs´i vigastuseks. Korduva eesmise õlaliigese nihestuse korral suureneb luuline haaratus nii abaluu eesmis-alumise liigeseõõnsuse kui ka õlavarreluu-pea piirkonnas. Lisaks võib kaasneda rotaatormanseti kõõluste rebend, mida esineb rohkem üle 40-aastastel patsientidel. Kirjanduse põhjal on rotaatormansetiga seotud vigastused alla 30-aastastel patsientidel harvad, esinemissagedusega 3–6%, valdavalt osalised ja liigesesisesed.

Õlaliigese kapsli ülemine osa on tihedalt seotud *m. supraspinatus'*e ja *m. infraspinatus'*e kõõlustega. Liigesekapsli ülemises osas eest-taha kulgevat kaarjat struktuuri nimetatakse *lig. semicirculare humeri´*ks (kliiniliselt rotaatorkaabel). Burkhart (1993) on kliiniliselt kirjeldanud rotaatorkaabli tähtsust rotaatormanseti vigastuste puhul „ripsilla“ fenomenina. Ishiara (2014) ja Pinkowski (2017) on biomehaanilistel uuringutel tõestanud, et ainuüksi ülemise liigesekapsli ja rotaatorkaabli kahjustus rotaatormanseti kõõluste vigastuseta omab olulist tähtsust õlaliigese eesmis-alumise ebastabiilsuse tekkel.

Õlaliigese kapsli ülemis-tagumise piirkonna struktuure on seni vähe uuritud ja verevarustust kirjeldatakse ainult üldiselt. Erinevates kirjandusallikates on välja toodud piirkonda verega varustavad arterid: *a. circumflexa humeri posterior*, *a. circumflexa scapulae* ja *a. suprascapularis*. Varasemates artiklites ei ole õlaliigese kapsli tagumis-ülemises piirkonnas asetsevate sidemeliste struktuuride verevarustust kirjeldatud.

Kirjanduse andmetel on noortel füüsiliselt aktiivsetel patsientidel traumaatilise õlaliigese eesmise nihestuse korral näidustatud kirurgiline ravi, sest nihestused korduvad kuni 94% juhtudest. Burkhart ja de Beer (2000) on kirjeldanud, et luukahjustuseta nihestusel esineb 6.5% patsientidest operatsioonijärgselt korduvnihestusi. Seoses sellega kerkib küsimus, kas tagumis-ülemise liigesekapsli kahjustused võivad olla korduvnihestuse üheks põhjuseks?

Hill-Sachs vigastuse korral teostatakse lisaks eesmiste kapsulolabraalsete struktuuride taastamisele Hill-Sachs'i luudefekti täitmine tagumis-ülemise liigesekapsli struktuuridega ja *m. infraspinatus´e* kõõlusega (*remplissage* protseduur). Varasemates artiklites pööratakse *remplissage* operatsioonitehnika kirjeldamisel pearõhk tugevale luulisele kinnitusele, arvestamata anatoomilisi kapslistruktuure ja nende verevarustust.

## Töö eesmärk ja ülesanded

Töö üldine eesmärk oli kirjeldada õlaliigese kapsli tagumis-ülemise piirkonna kõõluselis-sidemeliste struktuuride ja verevarustuse uurimistulemusi ja nende rakendamise võimalusi eesmise traumaatilise õlaliigese nihestuse kirurgilises ravis. Töös püstitati järgmised konkreetsed ülesanded:

1. Kirjeldada anatoomiliselt täpselt rotaatorkaabli (*lig. semicirculare humeri*) ja tagumis-ülemise õlaliigese kapsli ühenduse seost rotaatormanseti lihaste kõõlustega.
2. Uurida õlaliigese kapsli tagumis-ülemise piirkonna struktuuri ja verevarustust.
3. Kirjeldada õlaliigese tagumis-ülemise kapsulomuskulaarseid vigastusi eesmise traumaatilise õlaliigese nihestuse järgselt ja hinnata pärast operatsiooni kahe aasta möödudes patsientidel kliinilisi tulemusi.
4. Välja töötada *remplissage* operatsioonitehnika, lähtudes tagumis-ülemise õlaliigese piirkonna anatoomilistest struktuuridest ja nende verevarustusest.

## Materjal ja meetodid

Töö põhineb neljal erineval uuringul. Makroanatoomilisteks uuringuteks (I, II ja IV uuring) kasutati kokku 50 kesk- ja vanemaealise inimese õlaliigese preparaati (20 naist/30 meest), neist 16 õlga olid fikseeritud ja 34 fikseerimata. Veresoonte uuringuteks kasutati 13 fikseerimata õlaliigese preparaati, millel eelnevalt teostati veresoonte täitmine lateksmassiga. Uurimistöö see osa viidi läbi koostöös Lübecki Ülikooli Anatoomia Instituudiga ja kasutati annetajatelt saadud õlaliigeseid.

Kliiniline (III) uuring viidi läbi 16 sportlikult aktiivsel meessoost patsiendil, vanuses 16–25 aastat, keda opereeriti esmakordse traumaatilise eesmise õlaliigese nihestuse järgselt esimese kahe nädala (2–12 päeva) jooksul. Hinnati operatsioonil esinenud liigesesiseseid kahjustusi ja operatsioonijärgselt kahe aasta pärast kliinilisi tulemusi võrdlevalt tagumis-ülemise kõõluselis-sidemelise vigastusega ja vigastuseta patsientidel.

Operatsioonitehnika (IV) uuring viidi läbi 26-aastasel meespatsiendil, kellel esines Hill-Sachs'i ja rotaatorkaabli kinnituskoha vigastus. Operatsioonitehnika illustreerimiseks kasutati video- ja fotomaterjale operatsioonist, anatoomiliste struktuuride illustreerimiseks fotosid fikseerimata vasakust õlaliigesest.

## Järeldused ja kokkuvõte

Uurimuse põhjal tehti järgmised järeldused:

1. Rotaatorkaabli (*lig. semicirculare humeri*) tagumine kinnituskoht luule on sidemeliseks ühenduseks *m. supraspinatus*'e, *m. infraspinatus*'e ja *m. teres minor*'i kõõlustele. Õlaliigese kapsli ülemises osas on rotaatorkaabel tihedas kontaktis rotaatormanseti kõõlustega, suurem kontaktala tekib *m. supraspinatus*´e kõõlusega.

2. *A. circumflexa scapulae* tagumine haru annab verevarustuse ka liigesekapsli tagumis-ülemisele osa struktuuridele. *Lig. glenocapsulare* on anatoomiliselt konstantne liigesekapsli tagumis-ülemise osa sidemeline struktuur, mis paikneb *m. supraspinatus*´e ja *m. infraspinatus*´e kõõluste – lihaste piirkonnas ja koosneb ühest või kahest erinevast osast.
3. Õlaliigese kapsulomuskulaarseid tagumis-ülemise osa vigastusi esines pärast esmast eesmist traumaatilist nihestust üheksal opereeritud meespatsiendil kuueteistkümnest. Kõik vigastused haarasid alla 50% rotaatormanseti paksusest, mille kahjustatud piirkond puhastati ravi käigus. Kahe aasta pärast olid antud meetodil opereeritud rotaatormanseti vigastusega patsientide kliinilised tulemused võrdväärsed patsientidega, kellel antud vigastust ei esinenud.
4. Kui *remplissage* operatsioonitehnika käigus asetada õmblused horisontaalselt suunaga lateraalselt mediaalsele ja haarata kaasa rotaatorkaabli tagumine osa, siis see protseduur tagab kindla fiksatsiooni ja verevarustus ei katke liigesekapsli tagumis-ülemises ja *m. infraspinatus*´e kõõluse osas.

Kokkuvõttes täpsustasid antud anatoomiliste uurimuste tulemused õlaliigese kapsli tagumis-ülemise osa sidemelis-kõõluseliste struktuuride asetsust ja verevarustust. Kliiniline uuring näitas, et tagumis-ülemise rotaatormanseti alla 50% paksuse liigesesisese vigastuste puhastamine tagab head kliinilised tulemused ja õlaliigese stabiilsuse 2 aastat pärast operatsiooni. Analoogse kliinilise võrdleva uuringu andmeid kirjanduses meie andmetel ei leidu.

Seoses anatoomiliste struktuuride ja verevarustuse uute leidudega õlaliigese kapsli tagumis-ülemises osas töötasime välja ohutu ja stabiilse *remplissage* operatsioonitehnika haakuva Hill-Sachs vigastuse raviks. Antud operatsioonitehnikat on võimalik rakendada ka mittehaakuvate Hill-Sachs ja rotaatorkaabli tagumise osa vigastuste kirurgilises ravis. Antud metoodika kasutamine nendel juhtudel vajab veel edasisi kliinilisi uuringuid.

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