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Anatomical Structures Forming the Lateral Part of the Rotator Interval in the Human Shoulder Joint

Die Anatomie des lateralen Bereiches des Rotatoren-Intervalls im Schultergelenk des Menschen

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In memory of my father

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Anatomical and clinical abbreviations

BT	*Tendo capitis longi m. bicipitis brachii*
CT	computer tomography
CH	*Caput humeri*
DESS 3D	dual echo steady state three dimensional
GHJ	glenohumeral joint, *Articulatio humeri*
ISP	*M. infraspinatus*
LCG	*Ligamentum coracoglenoidale*
LCH	*Ligamentum coracohumerale*
LG	*Labrum glenoidale*
LGHI	*Ligamentum glenohumerale inferius*
LGHM	*Ligamentum glenohumerale medius*
LGHS	*Ligamentum glenohumerale superius*
LGHspir	*Ligamentum glenohumerale spirale*
LSCH	*Ligamentum semicirculare humeri*
LTH	*Ligamentum transversum humeri*
NA	number of acquisitions
MR	magnetic resonance
MRI	magnetic resonance imaging
PC	*Processus coracoideus*
PD WI	proton density weighted imaging
RC	rotator cuff
SL	slice thickness
SLAP lesion	superior labrum antero-posterior lesion
SSC	*M. subscapularis*
SSP	*M. supraspinatus*
TE	echo time
Te	cranial prolongation of the *Tendo m. pectoralis major*
TM	*M. teres minor*
TMA	*Tuberculum majus*
TMI	*Tuberculum minus*
TR	repetition time

TSG	*Tuberculum supraglenoidale*
WI	weighted imaging

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1. Introduction

The glenohumeral joint (GHJ) is the ball and socket joint and has the largest range of motion among all the joints of the human body. The GHJ is guided by the rotator cuff (RC) muscles, whose tendons extra-articularly reinforce the shoulder joint capsule. The static and dynamic stabilizers – the ligamentous-capsular structures and the rotator cuff muscles - provide stability to the shoulder. (Netter 2000, Fanghänel et al. 2003, Schiebler 2005, Schünke et al. 2005, Tillmann 2005).

In recent decades, orthopedic surgery on joints has developed rapidly and is now minimally invasive. Arthroscopic procedures have become the dominant method for resolving problems with the GHJ. At the same time, more detailed anatomic investigations allow for a better orientation in the narrow field of view available with arthroscopy.

Magnetic resonance (MR) imaging adds a new dimension to clinical findings on noninvasive visualization (Oxner 1997). MR imaging literature states that the usage of MR-arthrography gives a better depiction of shoulder joint structures and pathologic disorders. In addition to x-ray and computer tomography (CT), MR imaging makes it possible to get more detailed images of the capsular and ligamentous structures. This has made it possible to get diagnostic information about the anterior shoulder joint capsule, the rotator interval (space between the *M. subscapularis* and *M. supraspiantus* tendons) and partial tears in the tendons of RC muscles (Flannigan et al. 1990, Hodler et al. 1992, Merila et al. 2004, Krief 2005, Morag et al., 2005).

Due to advanced diagnostic and surgical methods nowadays, orthopedic surgeons and radiologists have been able to give more detailed descriptions of glenohumeral joint anatomy, which can be found in clinical literature.

1.1 Anatomy of the superior part of the shoulder joint capsule

1.1.1 Rotator interval

The antero-superior region of the GHJ capsule between the superior edge of the *M. subscapularis* (SSC) and the anterior edge of the *M. supraspinatus* (SSP), is clinically termed as the “rotator interval” and is not officially recognized in the anatomic literature as a topographic region (Netter 2000, Fanghänel et al. 2003, Schiebler 2005, Schünke et al, 2005, Tillmann 2005). Descriptions of the anatomic composition of the rotator interval are contentious. It has been described both as the weakest portion of shoulder joint capsule, claming that it has no reinforcing structures, (Steiner and Hermann 1989) and also as the thickest portion (Jost et al. 2000). The most detailed investigation of the rotator interval is given by Kolts and his colleagues (2002). In their description, the rotator interval consists of a complex of capsulo-ligamentous structures which are divided into the lateral, medio-superior and medio-inferior parts (Kolts et al. 2002). According to their description, the lateral part of the rotator interval is strengthened by the *Ligamentum semicirculare humeri* (LSCH) and anterior fibers from the *M. supraspinatus* which, together, are attached to the *Tuberculum minus* (TMI). The *Ligamenta coracohumerale* (LCH) *et coracoglenoidale* (LCG) form the medio-superior part and the medio-inferior part is reinforced by the *Ligamenta glenohumerale superius* (LGHS) *et medius* (LGHM) (Kolts et al. 2002).

Wermer et al. give another detailed, anatomic description of the lateral part of the rotator interval (2000). In their histo-anatomic study, they focused on describing the stabilizing sling for the long head of the biceps tendon that, according to their results, consists of transverse fibers (*Fasiculus obliquus*) and the *Ligamentum glenohumerale superius*. These were considered to be the main structures that form the stabilizing sling for the long head tendon of the biceps (Werner et al. 2000).

1.1.2 *Ligamentum glenohumerale superius*

Although the glenohumeral ligaments were first described by Flood in 1829, standard human anatomy has not recognized them as constant macroscopic structures until today. Contemporary anatomy textbooks and atlases (Thiel 1999, Netter 2000, Fanghänel et al. 2003 Schiebler 2005, Schünke et al. 2005, Tillmann 2005) describe the three different glenohumeral ligaments – *Ligamenta glenohumerale superius, medium et inferius* as unstable thickenings of the anterior joint capsule. Some authors find that the *Ligamenta glenohumeralia* are visible from the internal side of the shoulder joint capsule (Fanghänel et al. 2003) and others state that the unstable thickenings can be visualized by transillumination of the shoulder joint capsule (Thiel 1999). There are also authors (Rohen & Yokochi 1993) who do not mention the existence of the *Ligamenta glenohumeralia* at all. Therefore, in the official Terminologia Anatomica (1998) the superior, middle and inferior glenohumeral ligaments are not classified separately as single structures but all together as *Ligamenta glenohumeralia*.

Controversially, clinical orthopedic textbooks (DePalma 1983, Warren 1999,) and current publications (Clark 1990, Ferrari 1990, Clark and Harryman II 1992, Palmer et al. 1994, Steinbeck et al. 1998, Kolts et al. 2001, Pradhan et al. 2001, Burkhart 2002, Kolts et al. 2002, Ide et al. 2004) pay a lot of attention to the clinical anatomy of the *Ligamenta glenohumeralia* and describe them as stable macroscopic structures that are visible from the intra- and extra-articular sides of the shoulder joint capsule.

As there is no common agreement concerning the detailed anatomy of the *Ligamenta glenohumeralia*, a great variety of different opinions about the anatomy of each of ligament can be found in literature. The focus of the present study was on the *Ligamentum glenohumerale superius* (LGHS), which is described as a stable anatomical structure by the majority of clinical investigators.

One of the dominating opinions concerning the origin of the LGHS is that it arises from the upper pole of the *Cavitas glenoidalis* or from the *Tuberculum supraglenoidale* (TSG), which is just anterior to the origin of the *Tendo capitis longi m. bicipitis brachii* (BT) (DePalma 1983, Ferrari 1990, Warren 1999, Kolts et al. 2001, Burkhart 2002, Kolts et al. 2002).

Some descriptions of the origins of the *Ligamentum glenohumerale superius* state that the LGHS originates from the superior part of the *Labrum glenoidale* (LG) (Palmer et al. 1994, Steinbeck et al. 1998, Pradhan et al. 2001, Ide et al. 2004). Other authors have also mentioned that the LGHS has a connection with the *Ligamentum glenohumerale medium* (LGHM) at the point of its origin in the region of the *Tuberculum supraglenoidale* (DePalma 1983, Palmer et al. 1994, Steinbeck et al. 1998, Kolts et al. 2002, Ide et al. 2004).

Anatomists do not recognize the existence of the *Ligamentum glenohumerale superius* as a constant anatomic structure and therefore do not describe its origin or its insertion (Terminologia Anatomica 1998, Thiel 1999, Netter 2000, Fanghänel et al. 2003 Schiebler 2005, Schünke et al. 2005, Tillmann 2005). The majority of anatomic descriptions about the ligamentous structures within the rotator interval are limited to the *Ligamentum coracohumerale* with its insertion regions on the *Tuberculum majus et minus*. Yet, there are currently contrary anatomic and clinical publications that point out a tight connection between the LCH and the LGHS and that also separately describe the course and origin of the LGHS and its insertion region on the *Tuberculum minus* (DePalma 1983, Ferrari 1990, Steinbeck et al. 1998, Kolts et al. 2001).

The direct and oblique parts of the ligament are also recognized and their two points of insertion are described as the direct part at the *Tuberculum minus* and the oblique part at the *Ligamentum semicirculare humeri* (Kolts et al. 2002). Werner et al. (2000) describe the existence of a "*Fasciculus obliquus*", which is supposed to be one part of the stabilizing sling for the *Tendo capitis longi m. bicipitis brachii* (BT) that also strengthens the rotator interval. Both authors find that there are oblique fibers running over the intra-articular portion of the biceps tendon, with the difference being, that one describes them as the oblique parts of the LGHS (Kolts et al. 2002), the other finds that the obliquely running fibers belong to the "transverse band of the rotator cuff (*Fasciculus obliquus*)" (Werner at al. 2000).

1.1.3 *Ligamentum semicirculare humeri*

Recent orthopedic and anatomic studies have depicted a capsular ligamentous structure in the latero-superior shoulder joint capsule below the tendons of the *M. supraspinatus* (SSP) and the *M. infraspinatus* (ISP).

The bundles of collagen fibers with parallel orientation in the superior shoulder joint capsule run perpendicular to the longitudinal axis of the SSP tendon and were first described in the findings of histological investigations (Clark et al. 1990, Clark and Harrymann 2nd 1992). The ligamentous structure was identified as the deep extension of the LCH. These findings were macroscopically and histologically confirmed by Fallon et al. (Fallon et al. 2002).

Burkhart et al. (1992) gave an arthroscopic depiction of the morphologically described capsular structure in the superior shoulder capsule and named it the “rotator cable”. In addition, they proposed a biomechanical model of the tear in the rotator cuff, where the “rotator cable” acts as the loaded cable of a suspension bridge (Burkhart, 1992; Burkhart et al. 1993). This concept was also supported by a biomechanical study (Halder et al. 2002).

More detailed anatomical information about this structure was later attained from studies of embalmed shoulder joints. The name “*Ligamentum semicirculare humeri*” (LSCH) was proposed for the capsular ligament of the latero-superior shoulder joint capsule (Kolts et al. 2000, Kolts et al. 2002).

In spite of numerous morphological and clinical investigations, MR imaging literature on the detailed visualization of the capsular structures in the superior shoulder joint capsule is rarely found. Stoller et al. (2004) have so far been the only ones (!) who have published an MR image of the so-called rotator cable or LSCH.

On the other hand, there is constant diagnostic interest in introducing the recently found structures into clinical practice. In a recent study, sonography identifeid the so-called rotator cable on cadavers, resulting in the ligament in the superior shoulder joint capsule being confirmed by histological investigations (Morag et al. 2006).

1.2 Pathological seizures of the superior parts of the shoulder joint

1.2.1 Rotator cuff tear

Tears in rotator cuff (RC) muscles are common lesions in the superior part of the shoulder joint. They are classified as partial or complete, or otherwise known as full-thickness tears. The subtypes of partial tears are bursal, or articular side tears, and intratendineous tears (Fukuda 2003). Complete tears are classified into groups by the size of the tear or depending on how many of the RC muscles tendons are involved in the degenerative changes. A common view is that when the tear is localized only in the SSP tendon, and the diameter of the lesion is lesser than 3 cm, it is classified as small; it is moderate when two tendons have a tendon defect of 3 – 5 cm and large when the tear spreads to 3 – 4 tendons with a lesion size over 5 cm (Baker et al., 2003). Burkhart et al. made an important statement concerning the pathology of RC tears, which differs from common understanding (1992, 1993). Their description of the RC tear takes into consideration the existence of the “rotator cable”, otherwise known as *Ligamentum semicirculare humeri* (LSCH). The formation of the RC tear is compared to the suspension bridge structure, where the “rotator cable” acts like a loaded cable under tension from, and pulled medially, by the SSP (Burkhart 1992; Burkhart et al., 1993). Relying on this model, Burkhart also recommended that L-shaped and larger U-shaped tears should be repaired by first making side-by-side sutures to achieve a margin convergence and then completing the repair with an anchor fixation to the bone (Burkhart 2004).

1.2.2 Pulley lesion and anterior-superior impingement

The “pulley system” is a functional term for the tendinoligamentous sling in the lateral part of the rotator interval, which consists of four major structures. These four structures are the LCH, the LGHS, the anterior fibers of the SSP tendon and the superior fibers of the SSC tendon. At the intraarticular entrance of the bicipital groove, the LGHS and LCH fibers together form the reflection pulley for the long head of the biceps tendon (Werner et al., 2003; Habermeyer et al., 2004).

Habermeyer et al. (2004) divided the pulley lesions into four groups:

- first group – only the LGHS lesion
- second group – the LGHS and the SSP lesions
- third group – the LGHS and the SSC lesions
- fourth group – the LGHS lesion with the SSP and the SSC lesions

Statements in the research on the etiology and pathological mechanisms of pulley lesion are not cohesive (Gerber and Sebesta 2000; Habermeyer et al., 2004).

1.2.3 Superior labrum antero-posterior (SLAP) lesion

Lesions of the superior labrum are difficult to diagnose because the superior labrum attaches to the glenoid in a wide variety of ways (Gartsman and Hammerman 2000). Andrews et al. (1985) gave the first report on the pathological changes in the anterior-superior labral tissue in a group of high-level throwing athletes who were baseball players and javelin throwers.

Snyder et al. (1990) named the described pathological changes SLAP (superior labrum antero-posterior) lesions. They identified different degrees of the SLAP lesions in a retrospective study and worked out a system of classification:

- type I SLAP lesion – degeneration or fraying of the superior labrum without instability
- type II SLAP lesion – detachment of the superior labrum from the glenoid
- type III SLAP lesion – bucket-handle tear of the superior labrum
- type IV SLAP lesion – bucket-handle tear of the superior labrum that extends into the biceps tendon

The study by Maffet et al. (1999) added three types to the existing classification:

- type V SLAP lesion – antero-inferior Bankart lesion (anterior labrum detachment) that continues superiorly and includes separation of the biceps tendon from the glenoid
- type VI SLAP lesion – biceps tendon separation from the glenoid with an unstable flap tear of the labrum
- type VII SLAP lesion – the separation of the biceps with superior labrum from the glenoid that extends anteriorly beneath the middle glenohumeral ligament.

Recent analysis of SLAP lesions has lead to the conclusion that the superior labrum, the long head of the biceps, and the superior and middle glenohumeral ligaments work together to provide stability to the shoulder joint (Parentis et al., 2002).

1.2.4 Hill-Sachs lesion

Hill-Sachs lesions are postero-lateral bone defects of the humeral head. Classically, such lesions have been described as compression fractures of the humeral head and anatomic neck which occur when the glenohumeral joint (GHJ) becomes dislocated. Contemporary imaging techniques (arthroscopy, MR imaging and CT) have given new information about this lesion. One three-dimensional CT investigation of the bony structures of the GHJ with anterior instabilities showed that the Hill-Sachs lesion is located in the area of insertion of the *M. infraspinatus* and *M. teres minor* tendons (TM) (Stevens et al., 1999). The Hill-Sachs defect has also been found in 60% of patients with atraumatic GHJ instability (Werner et al., 2004). Some studies have pointed out that the depth of the defect does not correlate to the number of dislocations and that the size of the bone defect remains the same despite recurring dislocations (Wintzell et al., 1996; Ito et al., 2000).

2 Aims of the study

This study was inspired by recently published morphological findings on capsulo-ligamentous structures in the superior and anterior parts of the glenohumeral joint.

The new anatomical findings give a better understanding of previously described pathologic conditions like the biceps muscle tendon reflection pulley lesions, SLAP lesions, the formation of the Hill-Sachs defect and degenerative changes within rotator cuff tendons.

One of the structures involved in the formation of the biceps long head tendon pulley and the SLAP lesions is LGHS, which has an insufficient and controversial anatomic description in literature. In anatomy textbooks the *Ligamenta glenohumeralia* are commonly identified as unstable thickenings of the anterior shoulder joint capsule. (Netter 2000; Fanghänel et al., 2003; Schiebler 2005; Schünke et al., 2005; Tillmann 2005). Clinical literature either gives controversial descriptions of the origin, composition, insertion and relation of the LGHS with newly found capsular structures, or does not mention it at all (DePalma 1983, Palmer et al. 1994, Steinbeck et al. 1998, Werner et al. 2000, Ide et al. 2004, Stoller et al. 2004, Morag et al 2005). There is no morphological or clinical analysis of its relation to the previously described capsular structure – rotator cable, otherwise known as LSCH (Clark et al. 1990, Burkhart 1992, Clark and Harrymann 2nd 1992, Burkhart et al. 1993, Kolts et al. 2000, Kolts et al. 2002), within the superior shoulder joint capsule and the lateral rotator interval. Besides, this is the region that is frequently involved in different pathologies involving all ages of the population.

In spite of a lack of morphologic description of the LGHS, it is commonly marked on diagnostic MR images. The rotator cable, or so-called LSCH, is still missing from radiological diagnostics. Until now, there is only one (!) MR image of the rotator cable (Stoller et al. 2004) in connection with rotator cuff anatomy published.

This influenced interest in performing an additional morphologic investigation into MR imaging studies that involve not only the LSCH connection with the rotator cuff anatomy but also the composition of the lateral part of the rotator interval and the postero-superior insertion region of the LSCH.

In the lateral part of the rotator interval, both neighboring ligaments – LSCH and LGHS - are tightly connected with each other and take part in the reinforcement of the shoulder joint capsule. Therefore they are obviously both involved in the formation of the antero-superior shoulder joint pathologies.

The particular interest in the clinical importance of the LSCH comes from its involvement in rotator cuff pathologies in the superior part of the GHJ and from the fact that the posterior insertion region of this ligament might be connected with the formation of the Hill-Sachs lesion.

3 Materials and methods

This anatomical study is based on 26 shoulder joint specimens from 21 cadavers. Eight right and four left alcohol-formalin-glycerol fixed (absolute alcohol 38%, glycerine 24%, formaldehyde 4,75%, Fugaten® 9.5%, lysoformine 4,75%, demineralised water 19%) shoulder joints (age range 65 – 78 years) and eight right and six left non-fixed shoulder joint specimens (age range 52 - 82 years) were investigated.

Only a detailed anatomic dissection was performed on all the twelve fixed and five non-fixed (three right and two left) shoulder joint specimens. Nine fresh (five right and four left) shoulder specimens were examined with MRI and arthroscopy before anatomic dissection. Two shoulders from one cadaver were excluded from the study after the MRI and arthroscopy, because both of them had large rotator cuff tears with muscle degeneration and the glenohumeral joints were in subluxation. Two shoulders (one right, one left) were examined before anatomic dissection only with arthroscopy.

The human cadavers were dissected under permission of the "Gesetz über das Leichen-, Bestattungs- und Friedhofswesen (Bestattungsgesetz) des Landes Schleswig-Holstein vom 04.02.2005, Abschnitt II, § 9 (Leichenöffnung, anatomisch)". In this case it is allowed to dissect the bodies of the donators (Körperspender/in) for scientific and/or educational purposes.

3.1 Anatomic dissection

The muscles of the shoulder girdle were removed. The rotator cuff muscles, the intraarticular part of the biceps tendon and the *Mm. pectoralis major et minor* insertion tendons were dissected. The *Acromion* was cut from the *Spina scapulae* and removed together with the *Ligamentum coracoacromiale*. The *Bursa subacromialis* and the loose connective tissue was cleaned off of the muscles and tendons.

The rotator cuff muscles were separated from the shoulder joint capsule and the *Ligamentum coracohumerale*, the *Ligamentum coracoglenoidale*, the *Ligamentum glenohumerale superius* and the *Ligamentum semicirculare humeri* were dissected in fine detail.

3.2 Light microscopical investigation

Approximately 1,5 cm × 1 cm pieces of LGHS and LSCH were taken from three different parts of all of the fresh shoulder specimens: the origin, the insertion and the middle part of the ligaments. The material was fixed in 10% neutral buffered formalin and embedded in paraffin (Paraplast®). The histological slices with a thickness of 7 µm were stained after Trichrome Masson-Goldner with resorcin-fuchsin.

3.3 Magnetic resonance imaging of the shoulder

The shoulder specimens were examined by MRI on a 1.5 Tesla device (Somatom symphony®, Siemens, Erlangen, Germany). The shoulder coil was used on all specimens. MR arthrography was performed on all the seven shoulder specimens. MR arthrography was done under fluoroscopic guidance with the injection of 15-20 ml of a contrast solution (0.8 ml Magnevist® in 100 ml of saline). Standard axial, oblique coronal and oblique sagittal fat saturated views PD WI (TR 3000ms, TE 36 ms, SL 3 mm, Matrix (M) 224*512, number of acquisitions (NA) 2, TA (min) axial 3.18, oblique sagittal/coronal 3.54) , axial and oblique coronal T1 WI (TR 632 ms, TE 14 ms, SL 3 mm, M 256*512, NA 3, TA (min) axial 4.32, oblique coronal 3.46) and axial DESS 3D WI (TR 21.5 ms, TE 6.5 ms, SL 1.5 mm, M 217*256, NA 1, TA (min) 5.14) were used.

3.4 Arthroscopic examination

Shoulder arthroscopies were carried out through the posterior portal (between the supraspinatus and the infraspinatus muscles) with oblique optics at 30 degrees. The glenohumeral joints were distended with a 0,9% NaCl solution for the arthroscopies. The anterior and superior shoulder joint capsule and the muscle tendons of the rotator cuff were inspected. The ligamentous structures and rotator cuff tendons were photographed (Sony Colour Photo Printer Mavigraph).

3.5 Comparison of the results of anatomical dissection, magnetic resonance imaging and arthroscopy

The evaluation of the MR images was done together with two experienced radiologists. Since the LSCH was not previously described in radiological literature, both radiologists were introduced to pertinent LSCH anatomy by a demonstration of the LSCH in 5 gross-anatomic non-fixed specimens. The first MR imaging specimen was evaluated after the radiologists had seen the corresponding gross-anatomic specimens. The following 6 specimens were evaluated before anatomic dissection.

Arthroscopies were carried out without knowing the results of the MR imaging investigation. An experienced orthopaedic surgeon assisted the arthroscopic procedures.

The gross-anatomical dissection was done knowing only the results of the previously performed arthroscopy.

Finally, the results from the different methods were compared and analyzed.

4 Results

4.1 Normal anatomy and histology of the *Ligamentum glenohumerale superius*

4.1.1 Gross-anatomic description of the *Ligamentum glenohumerale superius*

The *Ligamentum glenohumerale superius* (LGHS) was found in all of the twenty-six shoulder joint specimens that were investigated. It was always connected with the *Ligamentum coracohumerale* (LCH) in its middle part (Figure 1).

The fibers of the *Ligamentum glenohumerale superius* were divided into two groups – direct and oblique fibers. In 24 of 26 cases, the "oblique" fibers of the LGHS originated in the *Tuberculum supraglenoidale* and arose together with the *Ligamentum glenohumerale medium* (LGHM) (Figure 2).

In two cases, when the LGHM was absent, the oblique fibers arose together with the direct fibers from the antero-superior labrum (Figure 3).

The "direct" fibers originated from the antero-superior and anterior *Labrum glenoidale* between 11 and 3 o'clock (Figure 4, 5).

In 24 cases, the arising anterior fibers of the "direct" part of the LGHS were in partly covered with the LGHM (Figure 2); the antero-superior fibers ran out from below the *Tendo capitis longi m. bicipitis brachii* (BT) (Figure 4a)

The direct fibers ran parallel with the *Tendo capitis longi m. bicipitis brachii* lying between the BT and the SSC (Figure 2, 4). They coursed with the overlying fibers of the LCH towards the *Tuberculum minus* (TMI), inserted partly onto it, and, after reaching the *Ligamentum semicirculare humeri* (LSCH), did not attach to it, but ran under it into the bottom of the *Sulcus intertubercularis* and made a bridge over the *Sulcus intertubercularis*, thus forming the superior part of the *Ligamentum transversum humeri* (LTH) (Figure 5).

The oblique fibers fused loosely with the overlying fibers of the LCH, coursed over the intraarticular portion of the BT and inserted on the LSCH (Figure 2, 4).

4.1.2 Light microscopy of the *Ligamentum glenohumerale superius*

The direct part of the *Ligamentum glenohumerale superius* showed the typical features of the dense connective tissue with parallel oriented bundles of collagen fibers in the main, middle part of the ligament (Figure 6a, b). The origin and insertion typically showed the characters of the fibrocartilagineous tissue (Figure 6c, d, e, f).

The main portion of the oblique component of the LGHS that arose from the *Tuberculum supraglenoidale* was composed of parallel oriented bundles of collagen fibers with the typical fibroblasts present in all the investigated parts (Figure 6a, b). When the LGHM was absent, the origin of the oblique component of the LGHS was in the superior *Labrum glenoidale* (LG) and the tissue was fibrocartilagineous with chondrocyte-like cells lying separate from each other, in pairs or rows (Figure 6c). At the place of insertion, the fibers of the oblique component interwove with the perpendicularly running fibers of the LSCH and therefore the fibers of the LGHS lost their course as an independent structure.

4.2 Normal, arthroscopic and MRI anatomy of the *Ligamentum semicirculare humeri*

4.2.1 Gross-anatomic description of the *Ligamentum semicirculare humeri*

The *Ligamentum semicirculare humeri* was present in all twenty-six shoulder joint specimens. It was always well distinguishable as an arched structure in the superio-lateral shoulder joint capsule despite its intra-capsular position.

The LSCH arose from the *Tuberculum majus et minus* and formed a semicircular arch ending on the posterior facet of the *Tuberculum majus*, between the insertion regions of the *M. infraspinatus* (ISP) and *M. teres minor* (TM) muscle tendons.

The LSCH was divided into three segments - anterior, middle and posterior.

The portion of the LSCH going from its origin to the anterior edge of the SSP was identified as the anterior part of the ligament. The anterior segment of the LSCH formed the lateral part of the rotator interval. In this particular region, the LCH fused into the LSCH and they were indistinguishable from one other in all twenty-six specimens examined (Figure 7). In the rotator interval, the fibres of the LSCH split into two layers – the superficial-medial and deep-lateral fibre layers (Figure 7). The anterior fibres of the SSP tendon fused with the superficial-medial layer of LSCH and coursed along with it until insertion. The insertion region of the superficial-medial layer of the LSCH was on the superior facet of the *Tuberculum minus*. At the insertion point the LSCH interwove with the SSC tendon and the *Ligamentum transversum humeri* in all investigated specimens (Figure 7, 8a). The deep-lateral layer of the LSCH coursed over the intertubercular groove and inserted into the anterior facet of the *Tuberculum majus* (Figure 7, 8a).

The segment of the LSCH under the SSP tendon formed the middle portion of the LSCH (Figure 8b). In this portion, the course of the ligament was perpendicular to the longitudinal axes of the SSP and ISP tendons. Inferior fibres from the SSP tendon interwove tightly with fibres of the LSCH, forming the capsular insertion of the SSP tendon. In this region, some of the SSP tendon fibres could not be separated from the LSCH and the joint capsule.

The fibres of the LSCH, covered by the ISP tendon, formed the posterior part of the ligament. The descending fibres curved latero-posteriorly and ended at the insertion region between the ISP and TM tendons on the posterior side of the *Tuberculum majus* (Figure 8c).

4.2.2 Magnetic resonance imaging findings and correlation with gross anatomic dissection results.

In six of seven specimens the LSCH or parts of the LSCH could be detected by MR imaging. The ligament or parts of the ligament were best seen on axially (DESS, T1 WI, PDW WI) oriented MR images.

In particular, the middle portion of the ligament was best identified on axial images as an anatomic structure with an intermediate signal (Figure 8e). The posterior part of the LSCH was recognized as a low signal intensity element of the capsule in two specimens (Figure 8e, 8f).

In one specimen with a partial tear of the SSP, the LSCH could not be identified on MR images. This correlated well with the gross anatomical dissection. In this specimen, the fibres of LSCH were detectable, but the borders of the LSCH were blurred and the LSCH was very thin compared to other specimens.

In two of seven specimens with full thickness tears of the SSP, the oblique coronal orientation showed a thickening of the middle LSCH region corresponding to a lateral tissue-defect above the *Caput humeri*. The thickening was interpreted as part of the LSCH. This correlated well with observations made during the anatomic dissection. In both instances, the LSCH were dislocated medially and surrounded by disorganized connective tissue (Figure 9).

In three of seven specimens, the LSCH was evaluated as a weak ligament on MR images. In these specimens, pathologies of the rotator cuff (2 partial tears of SSP) or the *Caput humeri* (1 Hill Sachs lesion with anterior capsular rupture) could be detected. All pathologies were confirmed by gross anatomical dissection. In each of these three specimens, the LSCH could be identified by dissection, but the macroscopic characteristics of the LSCH were weak.

A relatively strong LSCH was identified on MR images in one of seven specimens (Figure 8). This specimen showed no pathology of the shoulder on MR images or gross anatomic dissection.

4.2.3 Arthroscopic anatomy

The LSCH was clearly identified during arthroscopy of the GHJ specimens in all the investigated cases. Even in the two cases with full-thickness tears of the SSP, the shape and location of the arched edge of the rupture corresponded with the course of the fibers of the LSCH (Figure 10).

During arthroscopy through the standard posterior portal, the anterior and the medial parts of the LSCH became visible.

Two anterior insertion points of the LSCH could be identified; one on the *Tuberculum majus* exactly in front of the BT and the other on the *Tuberculum minus* antero-medial to the intraarticular portion of the BT (Figure 10a). The fibers of the medial part of LSCH were orientated perpendicularly to the SSP tendon fibers. This was clearly seen in the three cases with partial tears of the rotator cuff muscles on the articular side of the joint (Figure 10b). The joint capsule was destroyed, but the fibers of the tendon were still intact and their course was clearly visible.

The posterior part of the LSCH was not very clearly visible from the posterior portal.

4.2.4 Light microscopy of the *Ligamentum semicirculare humeri*

The histological study showed that the main part of the LSCH is formed by well-organized, parallelly oriented bundles of collagen fibers (Figure 11a, b). The ligamentous tissue is rich in elastic fibers that are mainly distributed among the fusion regions between the tendons of the SSP and the ISP muscles (Figure 11c).

Fibers from these tendons are entangled in the middle and posterior parts of the LSCH under the SSP and ISP tendons. The ligament fibers and the tendon fibers are perpendicular to each other (Figure 11a, b).

On the articular side of the LSCH, cartilage-like chondroid cells and fibrocartilage-like tissue was found in all the three parts of the LSCH (Figure 11d). The fibrocartilage tissue of the semicircular ligament built up the gliding surface on the intraarticular side.

4.3 Connection between *Ligamentum glenohumerale superius* and *Ligamentum semicirculare humeri*, description of the lateral part of the rotator interval

The lateral part of rotator interval is a triangular, capsular space above the intertubercular sulcus between the insertion tendons of the SSP and SSC. It is reinforced by the LGHS and the LSCH. Their fibers run perpendicular to each other in this region but do not intermingle with each other. The fibers of the LSCH that course towards the insertion region on the *Tuberculum minus* lie superficially above the fibers of the LGHS. The insertion fibers of the LGHS insert on the *Tuberculum minus,* partly course into the Sulcus intertubercularis and partly overbridge the sulcus, forming the upper part of the Ligamentum transversum humeri and, in this way, closing the osteofibrous canal of the BT.

5 Discussion

5.1 Materials and methods

The results of this investigation depend on a relatively limited number of investigated shoulder joint specimens and body donors with a small age range. The number of specimens was satisfactory for making conclusions regarding normal anatomy, but without describing any potential anatomic variations. The pathological changes, especially in rotator cuff (RC) were described by dissection or MR imaging because previous data on the pathologic conditions and complaints of shoulder problems from the body donors were not available. As MR imaging is a relatively expensive procedure, the number of specimens investigated by this method was limited.

5.2 *Ligamentum glenohumerale superius*

This current description of the *Ligamentum glenohumerale superius* (LGHS) differs from a lot of previous ones due to the additional anatomic information published during the last decades concerning the *Ligamentum coracohumerale* (LCH), the *Ligamentum semicirculare humeri* (LSCH), the *Ligamentum transversum humeri* and the *Ligamenta glenohumeralia*. In the present work, both fixed and fresh shoulder joint specimens were used to avoid an interpretation of the ligaments or their parts as artifacts of fixation. Only structures found onboth the fixed and the fresh specimens were taken into account as anatomic findings.

There is a common agreement in clinical literature that the LGHS is a constant anatomic structure that has a rate of appearance of at least 94% (Palmer et al. 1994; Steinbeck et al. 1998; Burkart et al. 2002; Ide et al. 2004).

Although the LGHS varied in the present study in shape and size, it was present in all the investigated specimens. It consisted of two main groups of “direct” and “oblique” fibres with different places of origin, courses of the fibres, and attachment regions, except in the cases without *Ligamentum glenohumerale medius* (LGHM). In these two cases, the place of origin of the direct and oblique fibers was at the superior *Labrum glenoidale*. The *Ligamentum glenohumerale superius* was tightly connected to the overlaid *Ligamentum coracohumerale*.

Clinical literature and some current publications state that the LGHS arises from the *Tuberculum supraglenoidale* and the upper pole of the glenoid cavity (DePalma 1983, Warren 1999, Ferrari 1990, Kolts et al. 2001, Burkart 2002, Kolts 2002). The other authors have stated that the LGHS arises from the superior labrum at the 1 o'clock position (Palmer et al 1994, Steinbeck et al 1998, Ide et al 2004).

Controversial findings on the origin of the LGHS are obviously due to different methods of investigation. Studies stating that the LGHS arises from the superior labrum, have mainly focused on the visualization of the *Ligamenta glenohumeralia* on the intra-articular side of the anterior shoulder joint capsule (Steinbeck et al. 1998, Ide et al. 2004) or have evaluated data from the MR images with arthrography (Palmer et al. 1994).

Papers stating that the LGHS arises from the *Tuberculum supraglenoidale* have described the extra-articular side of the shoulder joint capsule and placed their main focus on relations with the other strengthening glenohumeral structures of this region (Ferrari 1990, Kolts et al. 2001, Kolts et al. 2002).

The present study supports both previous descriptions. The extra- and intraarticular complex investigation showed that there are two different regions of origin of the LGHS fibers that may be divided into two groups: direct and oblique fibers. The "oblique fibers" of the LGHS arise from the *Tuberculum supraglenoidale* and the "direct" fibers begin at the *Labrum glenoidale* between 11 and 3 o'clock.

At the point of origin, the LGHS is intimately connected with the LGHM and also partially covered by it. This has given rise to the opinion that the LGHS and LGHM together originate in the *Tuberculum supraglenoidale*.

The researchers who have stated that the LGHS originates in the *Labrum glenoidale* have also mentioned the existence of anatomic association between the LGHS, the superior labrum and the origin of the *Tendo capitis longi m. bicipitis brachii* (BT) (Palmer et al. 1994, Steinbeck et al. 1998, Pradhan et al. 2001, Parentis et al. 2002, Ide et al. 2004). This statement is fully supported by the results of the present study. The direct fibers of the LGHS always originated from the *Labrum glenoidale*; in the two cases where the LGHM was absent, the oblique fibers also arose from the *Labrum glenoidale*.

The relationship between the LCH and the LGHS has been poorly studied. The lack of an officially recognized anatomy of the LGHS and the different anatomic descriptions concerning the anatomy of the LCH (Weinstabl et al. 1986, Ferrari 1990, Kolts et al. 2000, Kolts et al. 2002) may be the causes of the different anatomic descriptions. In the middle part, the two ligaments are closely connected to each other and the anatomic course of both ligaments could be recognized as one. This has obviously predetermined a variety of anatomical considerations concerning their anatomy, since the ligaments were not separated from each other before the anatomic description was made.

In recent decades, a lot of new additional information about the ligaments of the shoulder joint capsule has been published. It has influenced a rather rapid development of the investigation of newly found ligamentous structures and their connections with officially recognized ones.

Some articles, describe the existence of oblique fibers (Kolts et al. 2002) or the *"Fasciculus obliquus"* (Werner et al. 2000) in the antero-superior shoulder joint capsule. According to these works and our present results, the descriptions given by Werner et al. (2000) and Kolts et al. (2002) support the existence of the "oblique" part of the LGHS. In addition, the newly found "transverse fibers of the rotator cuff" (Clark 1990, Clark and Harryman 2nd 1992) - the "rotator cable" (Burkhart et al. 1993) or the *Ligamentum semicirculare humeri* (Kolts et al. 2002) serves as an insertion location for the oblique fibers of the LGHS instead of the *Tuberculum minus* (where the direct fibers attach).

The results of the present study correspond with the results of the previous researchers (Ferrari 1990, Steinbeck et al. 1998, Kolts et al. 2002), who mainly used a gross anatomic approach, dissecting the ligamentous structures in fine detail. The gross anatomic approach made it possible to separate the LCH from the underlying LGHS. This excluded the possibility that those two ligaments are interpreatated as one. Separation of the LCH from the LGHS made it possible to divide the LGHS into direct and oblique parts with a different origin, course and insertion regions.

The actual study supports the statements that the LCH, running into the "rotator cable" (Burkhart et al. 1993) or the LSCH (Kolts et al. 2002) or the "transverse band of the rotator cuff (*Fasciculus obliquus*)" (Clark 1990, Clark and Harryman 2nd 1992, Werner et al. 2000) does not attach directly to the *Tubercula minus et majus* of the *Humerus* (Thiel 1999, Netter 2000, Fanghänel et al. 2003 Schiebler 2005, Schünke et al. 2005, Tillmann 2005). The current results show that the LCH attaches to the LSCH and reaches the *Tuberculum minus* together with the semi-circularly running fibers. This means that the LGHS inserts into the *Tuberculum minus* directly but the fibers of the LCH reach the *Tuberculum minus* indirectly and first fuse with the anterior part of the LSCH, which overlays the insertion fibers of the LGHS.

The insertion region of the LGHS is commonly described as the *Tuberculum minus* (Ferrari 1990, Steinbeck et al. 1998, Kolts et al. 2001, Burkart et al. 2002). Werner et al. (2000) have added that a U-shaped sling crossing under the biceps tendon and inserting into the proximal aspect of the intertubercular groove formed at the insertion region the LGHS.. The actual study shows that the “U- shaped sling” is formed by the direct fibers of the LGHS that partly insert into the *Tuberculum minus* and into the bottom of the intertubercular groove and partly overbridge the *Sulcus intertubercularis,* forming the upper part of the *Ligamentum transversum humeri*.

According to current results, the connection of the LGHS with the “fasciculus obliquus” pointed out by Werner et al. (2002) is located at the anterior part of the LSCH (Burkhart et al 1993; Kolts et al.2002) that overlays the direct fibers of the LGHS at the insertion region.

Considering the origin of the LGHS from the antero-superior *Labrum glenoidale*, the course within the rotator interval and the tight connection with the LSCH, it can obviously be assumed that it may influence the formation of the *Labrum glenoidale* and other glenohumeral joint pathologies, especially in the rotator interval.

5.3 *Ligamentum semicirculare humeri*

These current results based on twenty-six shoulder joint specimens confirm the presence of the *Ligamamentum semicirculare humeri* (LSCH) in the latero-superior shoulder capsule as an independent anatomic structure. The ligament was visible in all dissected specimens and in six of seven cases on MR images.

The previous studies on fibers in the superior-lateral shoulder joint capsule locate the posterior insertion point of the LSCH between the *M. infraspinatus* (ISP) and *M. teres minor* (TM) tendons (Burkhart et al., 1993; Clark et al., 1990; Clark and Harryman, 1992; Kolts et al., 2000, Kolts et al., 2002). This was also confirmed by the present results. As to the anterior insertion, most authors have stated that LSCH crosses the *Tendo capitis longi m. bicipitis brachii* (BT) and inserts into the *Tuberculum minus* (Burkhart et al., 1993; Clark et al., 1990; Clark and Harryman, 1992). The actual results confirm the previous ones, and also describe the LSCH as having two insertion points anteriorly – the superficial-medial fibers on the *Tuberculum minus* and the deep-lateral fibers on the *Tuberculum majus*. This statement supports the results of observations made on embalmed specimens (Kolts et al., 2000, Kolts et al., 2002).

The actual anatomical findings also support the previous statement that the *Ligamentum coracohumerale* (LCH) does not insert into the *Tuberculum majus et minus* of the *Humerus*, but rather fuses into the LSCH (Kolts et al., 2000, Kolts et al., 2002). The LSCH and LCH are closely related structurally and functionally and they form the lateral and superior parts of the rotator interval. In spite of several reports in current literature of new findings on the ligaments of the shoulder joint, anatomical textbooks and atlases (Fanghänel et al., 2003; Schiebler 2005; Schünke et al., 2005; Tillmann 2005) still state that the LCH inserts into the *Tuberculum minus et majus* and not into the semicircular capsular ligament. As the existence of the LSCH has not been officially recognized by the Terminologia Anatomica (1998), an official anatomical description of the LSCH is also missing. The old statement on the insertion of the LCH might have been predominant for so long due to the fact that the anterior fibers of the LSCH were originally recognized as the insertion fibers of the LCH (Clark et al., 1990; Clark and Harryman, 1992).

A cleavage in the anterior portion of the LSCH creates an additional cover for the superior part of the intertubercular sulcus. The superficial-medial layer of the LSCH is associated with the *M. subscapularis* (SSC) tendon and the *Ligamentum transversum humeri* at its insertion point. The LSCH forms a gradual changeover between the *Ligamentum transversum humeri* and the rotator interval. It is rather likely that the described complex (*Ligamentum transversum humeri* and LSCH) plays an important role in the fixation and stabilization of the BT in the *Sulcus intertubercularis*.

Current MR imaging literature states that the usage of MR-arthrography provides a better depiction of the partial tears in the rotator cuff on its articular surface (Chaipat and Palmer 2006; Waldt et al., 2007). This method also makes it possible to get detailed images of the anterior capsular structures (Merila et al., 2004).

In the actual study, the findings of the MR imaging correlated well with the results of the gross anatomical dissection, showing that there are different characteristics of the LSCH. Despite the limitations of spatial resolution occurring with MR imaging, especially for very small anatomic structures, it was possible to detect the LSCH or parts of the LSCH in six of seven specimens using standard imaging sequences.

The MR study was limited by the small number of non-pathological specimens. Pathologic findings were found in six of seven shoulder specimens, particularly rotator cuff tears. These were found on the MR images and confirmed by dissection. This could be one reason why the ligament had a slightly different appearance on the MR images than after gross dissection. It is still unknown how the LSCH is involved in, and affects degenerative or posttraumatic shoulder disorders.

The curved and semicircular course of the LSCH could be one explanation of why the anterior and posterior parts of the LSCH are not very easily detected. Its close, anatomical relationships to the BT, LCH, SSP and capsular structures makes it more difficult to depict the anterior parts of the LSCH than the posterior and middle parts of the LSCH.

There is good contrast resolution between intra-articular fluid and soft tissue structures on the superior capsule, especially in the supine position. In this area, the LSCH courses partly across the plane of the MR images with a transverse orientation. As a result of the partial volume effect high contrast areas on the MR arthrography, it was possible to recognize the fibers of the middle portion of the LSCH. The LSCH was mainly detected as a structure of hypointense to intermediate signal intensity.

As there is apparently no MR imaging literature describing the existence of the LSCH, it is not possible to compare current results with any other investigation. According to the present results, MR imaging can be successfully used for a more detailed interpretation of the superior-lateral shoulder joint capsule. The attempt to visualize the normal anatomy of the previously described ligament of the superior shoulder joint capsule on the MR images occasionally provided additional information about the involvement of the ligament in the pathologic formation of rotator cuff tears. The role and diagnostic value of the visualization of the LSCH in other pathologic conditions remains unclear due to the lack of sufficient diagnostic and clinical experience.

5.4 Rotator cuff tears

Classically, the rotator cuff (RC) tears have been described as traumatic or degenerative detachments of the rotator cuff muscles from the *Humerus*. In addition to this classical understanding, Burkhart's hypothesis (Burkhart 1992; Burkhart et al., 1993) claims the existence of a rotator cable (LSCH) that acts as a suspension bridge in RC tears. This hypothesis has been confirmed by a biomechanical study by Halder et al. (2002). Later investigations have found that the morphological base of the rotator cable is a semicircular capsular ligament within the superior shoulder joint capsule named the *Ligamentum semicirculare humeri* (Kolts et al., 2000, Kolts et al., 2002). In the present study, it was also possible to detect a medially dislocated LSCH in the specimens with a full-thickness tear in the SSP tendon. This gross anatomy finding provides a base of evidence for the suspension bridge model.

The results of the present study confirm Burkhart's statement that the location of a rotator cuff tear is more important than the size of the tear (Burkhart et al., 1993). The location of the tear predetermines whether the LSCH is intact or not. If the LSCH is intact after the formation of the SSP and ISP tear, the LSCH is pulled medially by the force of the muscle tension in the SSP and ISP. The form of the defect on RC tears is predicted by the semicircular form of the LSCH and the remnants of the SSP and ISP tendons. Therefore the complete tear of the SSP tendon has a semicircular, Y-shaped form (Kolts 1992).

5.5 Pulley lesion and anatomy of the lateral part of the rotator interval

Previous publications about the reflection pulley of the biceps tendon in the lateral part of the rotator interval states that the structures forming it are the LCH, the LGHS and the tendons of the SSP and the SSC (Werner et al. 2000; Werner et al., 2003; Habermeyer et al. 2004). Werner et al. have made a histoanatomical study of the morphology of this stabilizing sling. They gave a detailed description of the formation of the pulley: it is mainly formed by fibers from the LGHS along with fibers from the LCH in connection with the so called *Fasiculus obliquus*. The origin of the *Fasiculus obliquus* fibers is not described in their studies. According to their schematic drawings, it corresponds to the course and position of the fibers of the LSCH in the upper part of the GHJ. The course of the continuation of the *Fasiculus obliquus* fibers to the anterior shoulder joint capsule under the SSC tendon correspond to the course of the recently described *Ligamentum glenohumerale spirale* (Kolts et al. 2001, Merila et al. 2002) which partly arises from the *Tuberculum infraglenoidale* and has historically been named as the *Fasiculus obliquus* (DeLorme 1910). Therefore the term *Fasiculus obliquus* to name the fibers in the superior part of the shoulder joint capsule is confusing. According to the present results, the *Fasiculus obliquus* named by Werner et al. (2000) is obviously the rotator cable (Burkhart et al. 1992, 1993) or the LSCH (Kolts et al., 2000, Kolts et al., 2002).

Relying on the current results and on a previous anatomic study done by Kolts et al. (2000, 2002), it is possible to conclude that the LCH is not involved in the formation of the so-called “pulley”, because it does not insert into the *Tuberculum minus,* but rather into the LSCH.

The classification of Habermeyer et al. (2004) for pulley lesions describes either isolated LGHS tears, or tears associated with tears in the LCH and the SSP, and in the tendons of the SSC muscles.

The essential problem which results from the formation of the pulley lesion is the instability of the BT (Habermayer et al. 2004). Taking into consideration the present description of the structures that form the pulley region, it is difficult to confirm the existence of an isolated LGHS tear. According to the anatomic composition of the lateral part of the rotator interval, tears of the LGHS must cause lesions of the SSC tendon, because the *Ligamentum transversum humeri* is partly composed of the SSC tendon fibers and, superiorly, also the LGHS fibers. A remarkable medial dislocation of the BT also injures the LSCH which has its SSP fibers running to the *Tuberculum minus*. In the case of a lateral dislocation of the BT, the *Ligamentum transversum humeri,* as well as fibers from the LGHS and the SSC tendon, must be injured together with the deep-lateral fibers of the LSCH and the SSP tendon.

5.6 Superior labrum antero-posterior (SLAP) lesion

Superior labrum antero-posterior (SLAP) lesions have been described as BT and superior labrum lesions. A detachment, or fraying, of the superior labrum always exists in the case of SLAP lesions (Snyder et al. 1995). Relying on actual results, it is possible to conclude that the superior labrum might be detached from the glenoid not only by the fibers of the BT but also by the biomechanical overload of the LGHS. So it is possible to conclude that the SLAP lesions can be characterized as complex injuries of the LGHS and the BT.

5.7 Hill-Sachs lesion

The most common bony lesion as pertains to shoulder instability is the Hill-Sachs lesion. It is a bony defect on the postero-lateral side of the humeral head and it is supposed to be caused by an impression of the humerus onto the anterior glenoid rim during anterior dislocation.

The development of imaging diagnostics and arthroscopic surgery improved understanding of the localization of the Hill-Sachs lesion.

A three-dimensional reconstruction of CT images of anteriorly unstable shoulders specified the location of the Hill-Sachs lesion on the border of the articular surface and the posterior edge of the *Tuberculum majus* (Stevens et al. 1999), located approximately at the insertion points of the tendons of the ISP and the TM. Recent studies and present results have confirmed that this is the region of the posterior insertion of the LSCH.

Based on this CT-imaging study and the current results, it is possible to build up a hypothesis, that the Hill-Sachs lesion is not only a bony lesion but it is also obviously combined with the posterior insertion lesion of the LSCH. The cause of the bony lesion might be the avulsion of the posterior part of the LSCH from the *Humerus*.

Studies on atraumatic instability and recurrent dislocations of the glenohumeral joint have pointed out that there is no correlation between the number of the dislocations and the depth of the lesion (Wintzell et al., 1996; Ito et al., 2000; Werner et al., 2004).

6 Summary

6.1 Summary

During the last decades, diagnostics and medical treatment of shoulder joint disorders has developed rapidly and passed through a lot of changes. Most of the disorders that need surgery can be treated endoscopically instead of the previous, open surgery. Methods like MR and CT with arthrography have also remarkably improved the possibility of a proper, medical diagnosis.

New clinical findings and needs have also contributed to the development of the normal, macroscopic anatomy of the shoulder joint. Despite this, there are still controversies in the morphologic and clinical sciences concerning the ligamentous structures of the glenohumeral joint. The most well-known problem is the question of the existence or non-existence of the glenohumeral ligaments. Clinically, they are known and recognized as stable macroscopic structures that are diagnosed and medically treated. Normal anatomy, on the contrary, describes them as unstable thickenings of the anterior glenohumeral joint capsule.

Recent clinical finding on state that the superior shoulder joint capsule is the so-called „rotator cable“, which has been morphologically described as the *„Ligamentum semicirculare humeri“*. It is a semicircular, arched, capsular structure in the superior shoulder joint capsule under the *M. supraspinatus* and *M. infraspinatus* tendons, coursing perpendicularly with the muscle tendons of the rotator cuff.

These clinical and morphological developments have influenced the finding and description of new pathological conditions, and therefore some formerly known disorders have been described in more detail. The development of arthroscopic surgery has lead to a description of the *superior labrum antero-posterior* (SLAP) and the so-called *biceps pulley* lesions within the lateral part of the rotator interval.

The most common problems concerning shoulder pathologies that influence the ability to work and the quality of life, are the painful problems associated with ruptures in the tendons of the rotator cuff muscles. Contemporary morphological investigations have influenced the development of medical treatments for the ruptures and new surgical techniques and methods are constantly introduced into clinical praxis.

The aim of the present study was to get a detailed, anatomic depiction of one of the most complex regions in the shoulder joint – the lateral part of rotator interval - and to investigate the key structures of this region using MR imaging techniques and arthroscopy.

The study was carried out on cadavers, of which twelve were fixed and fourteen were fresh shoulder joint specimens. The main methods of investigation were anatomic dissection and MR imaging studies, combined with the arthroscopic examination of the specimens before the anatomic dissection. Gross anatomic findings were supported by the histological investigation of the material. The results achieved by the different methods of investigation were compared with each other and summarized.

The lateral part of the rotator interval is composed of two ligamentous structures - the *Ligamenta glenohumerale superius* (LGHS) *et semicirculare humeri*(LSCH).

In anatomy textbooks, the LGHS is described as an unstable thickening of the anterior shoulder joint capsule. On the contrary, radiological and clinical literature describes the LGHS as a certain and stable ligamentous structure. In the present study, we found that the LGHS is a constantly present structure with direct and oblique fibers that have certain origin and insertion regions. The direct fibers arise from the superior labrum (in connection with the long head tendon of the bicep's brachii muscle). The oblique fibers of the LGHS begin together with the *Ligamentum glenohumerale medius* at the *Tuberculum supraglenoidale*. In the cases where the *Ligamentum glenohumerale medius* is absent, the oblique fibers of the LGHS begin together with the direct fibers from the *Labrum glenoidale*. The insertion area of the direct fibers is at the *Tuberculum minus* and in the *Sulcus intertubercularis.* The direct fibers of the LGHS also partly overbridge the intertubercular groove and form the superior part of the *Ligamentum transversum humeri*. The oblique fibers of the LGHS run over the intraarticular part of the *Tendo capitis longi m. bicipitis brachii* and fuse under the *Ligamentum coracohumerale* with the *Ligamentum semicirculare humeri*.

Relying on the anatomic observations, and taking into consideration the previously published clinical studies, it is possible to assume that the LGHS has an important role in forming the pulley for the biceps long head tendon, and that it is directly involved in the formation of SLAP.

Clinical articles also name the *Ligamentum semicirculare humeri* (LSCH) as the "rotator cable". It is a little-known ligamentous structure within the superior glenohumeral joint capsule. The first descriptions of the "rotator cable" were done by orthopedic surgeons during arthroscopic operations, who primarily described it as a ligament. Later anatomic studies on embalmed shoulder joints described the "rotator cable" as a new capsular ligament of the superior shoulder joint capsule, but did not give a detailed description of its origin and relation to the LGHS within the lateral rotator interval.

Until today, there is only one published MR image of the LSCH. The aim of the current study was to get a detailed anatomical description of the LSCH on fresh cadavers and to identify it with MR imaging and by arthroscopy.

On six out of the seven specimens that were studied with MR imaging, it was possible to identify the entire LSCH, or some parts of it. An arthroscopic investigation was carried out on nine specimens and it was possible to identify the LSCH from the intra-articular side in all cases. Results of the anatomic dissection of embalmed shoulder joints correlated with the results achieved on the fresh specimens and results of the arthroscopic and MR imaging.

The *Ligamentum semicirculare humeri* arises anteriorly from two areas: the superior facet of the *Tuberculum minus* and the anterior facet of the *Tuberculum majus* just above the intertubercular groove. It makes an arch under the *M. supraspinatus* and *M. infraspinatus* tendons, coursing posteriorly and perpendicularly with the longitudinal axes of the tendons. The insertion region of the ligament is on the posterior facet of the *Tuberculum majus* between the insertion of the *Mm. infraspinatus* and *teres minor* tendons.

An evaluation of the glenohumeral joints with rotator cuff muscles tears was performed and the role of the LSCH in the formation, the shape, and the size of the tear was analyzed. Relying on anatomic observation, it is possible to conclude that the presence of the LSCH causes the full-thickness ruptures to have a Y-shape, and that the size of the rupture depends on the load adjusted to the LSCH by the muscle forces of the *Mm. supra- et infraspinatus*.

The lateral part of rotator interval is formed by the LGHS and LSCH. In this region, they run perpendicularly to each other, but the ligaments do not fuse. The LSCH and LGHS form a "roof" over the intertubercular groove and are tightly connected with the superior edge of the *M. subscapularis*, the anterior edge of the *M. supraspinatus* and the *Ligamentum trans-*

versum humeri. These structures build up a complex that fixes and stabilizes the biceps long head tendon in the *Sulcus intertubercularis* and covers the intraarticular part of the tendon.

6.2 Zusammenfassung

Die Anatomie des lateralen Bereiches des Rotatoren-Intervalls im Schultergelenk des Menschen

Einleitung

Im Verlauf der vergangenen drei Jahrzehnte haben sich die Diagnostik und Behandlung von Erkrankungen des Schultergelenks weiter entwickelt und eine Vielzahl von Verbesserungen erfahren. Die meisten Erkrankungen, die chirurgische Eingriffe erfordern, können nun arthroskopisch behandelt werden, statt wie vorher üblich in offener Chirurgie. Die modernen Untersuchungsmethoden der Magnetresonanz- und der Computertomographie haben in Verbindung mit der Arthrographie zu einer bemerkenswerten Verbesserung der Diagnostik geführt.

Auch das Wissen über die makroskopische Anatomie des Schultergelenks hat im Gefolge der modernen klinischen Untersuchungen und Erkenntnisse an Details hinzugewonnen. Trotzdem bestehen weiterhin gegensätzliche wissenschaftliche Auffassungen zwischen den Morphologen und den Klinikern hinsichtlich des Bandapparates (und seiner Details) des Schultergelenks. Eine Hauptfrage besteht im Vorhandensein oder dem Fehlen der *Ligamenta glenohumeralia*. Bei den Klinikern sind sie bekannt als stabile Strukturen, die identifiziert und behandelt werden können. In der normalen Anatomie werden sie dagegen als zarte, instabile Verstärkungen der vorderen Kapsel des Schultergelenks betrachtet.

Zu den neueren, klinischen Beobachtungen an der Gelenkkapsel gehört das sogenannte „Rotator cable“, das morphologisch *Ligamentum semicirculare humeri* genannt wird. Dieses ist eine im halbkreisförmigen Bogen verlaufende Bandstruktur der oberen Gelenkkapsel, die direkt unter den Sehnen der *Mm. supraspinatus et infraspinatus* liegt und diese rechtwinklig unterquert.

Die neueren Beobachtungen und Erkenntnisse zur Klinik und Morphologie des Schultergelenks führten zu detaillierteren Beschreibungen bekannter Störungen und zur neueren Bewertung der pathologischen Abläufe.

Durch die Einführung der arthroskopischen Schulterchirurgie konnten die Verletzungen des „Superior labrum antero-posterior = SLAP“ und des sogenannten „Biceps pulley“ im lateralen Bereich des „Rotator Interval“ genau erkannt werden.

Das Hauptproblem aller Schultergelenksveränderungen, die die Arbeitsfähigkeit und die Lebensqualität herabsetzen, sind die außergewöhnlichen Schmerzen bei Sehnenrupturen der Muskeln der Rotatorenmanschetten. Zeitgleiche morphologische Untersuchungen der Rotatorenmanschette haben maßgeblich die Behandlung der Sehnenrupturen und die Entwicklung neuer chirurgischer Techniken beeinflusst und zu ihrer Einführung in die klinische Praxis beigetragen.

Ziel der Untersuchung

Das Ziel dieser Studie bestand darin, eine detailreiche, anatomische Beschreibung einer der komplexesten Regionen des Schultergelenks, des lateralen Anteils der Rotatorenmanschette, zu erhalten und die klinisch bedeutsamen Strukturen dieser Region durch Magnetresonanztomographie und Arthroskopie zu untersuchen.

Material und Methoden

Diese Studie wurde an anatomischen Präparaten von Körperspendern durchgeführt. Es wurden zwölf konservierte und vierzehn frische Schultern untersucht.

Im wesentlichen wurden sorgfältigste anatomische Präparationen und Magnet-resonanztomographische Darstellungen verglichen; die frischen Schultern wurden vor der anatomischen Präparation arthroskopisch untersucht. Die makroskopischen Ergebnisse wurden durch histologische Untersuchungen ergänzt.

Ergebnisse und Diskussion

Der seitliche Anteil des „Rotator Interval" besteht aus zwei Bandstrukturen, den *Ligamenta glenohumerale superius* (LGHS) *et semicirculare humeri* (LSCH).

In den anatomischen Lehrbüchern wird das *Ligamentum glenohumerale superius* als schwache Verstärkung der vorderen Gelenkkapsel des Schultergelenks beschrieben. Im Gegensatz dazu wird dieses Band in der radiologischen und klinischen Literatur als umschriebene und stabile Bandstruktur betrachtet.

In dieser Studie konnte festgestellt wirden, dass das LGHS eine sehr konstante Struktur ist, die mit direkten und schrägen Fasern an exakt zu bestimmenden Punkten entspringt und inseriert. Die gerade verlaufenden Fasern entspringen von der oberen Gelenklippe (in unmittelbarer Nähe zur Ursprungssehne des langen Bizepskopfes). Die schräg verlaufenden Fasern entspringen zusammen mit dem *Ligamentum glenohumerale medius* am *Tuberculum supraglenoidale*. In jenen Fällen, in denen das *Ligamentum glenohumerale medius* fehlt, entspringen die schräg verlaufenden Fasern zusammen mit den gerade verlaufenden Fasern vom *Labrum glenoidale*. Die geraden Fasern inserieren sowohl am *Tuberculum minus humeri* als auch im *Sulcus intertubercularis*; ein Teil dieser Faserzüge überbrückt die Rinne zwischen den Tubercula und bildet somit den oberen Teil des *Ligamentum transversum humeri*. Die schrägen Fasern dieses Ligaments kreuzen den intraartikulären Teil der langen Bizepssehne und vereinigen sich unter dem *Ligamentum coracohumerale* mit den Fasern des *Ligamentum semicirculare humeri*.

Auf der Basis der anatomischen Ergebnisse und unter Berücksichtigung der vorliegenden klinischen Literatur kann man schlussfolgern, dass das *Ligamentum glenohumerale superius* entscheidend an der Ausformung der Umlenkung der langen Bizepssehne beteiligt ist und damit auch am Zustandekommen der SLAP-Läsion.

Das *Ligamentum semicirculare humeri* (LSCH), wird in klinischen Artikeln englisch „Rotator cable" genannt. Diese bandartige Struktur innerhalb des oberen Anteils der Schultergelenkskapsel ist relativ unbekannt. Erste Beobachtungen des „Rotator cable" wurden von orthopädischen Chirurgen bei Arthroskopien gemacht, anfangs jedoch nicht als ein Ligament erkannt. Später wurde es auf der Basis anatomischer Präparationen konservierter Schultergelenke als ein neues Verstärkungsband der oberen Gelenkkapsel identifiziert. Allerdings gab es keine exakten Beschreibungen seines Verlaufes und seiner topographischen Beziehung zum *Ligamentum glenohumerale superius* innerhalb des lateralen Rotator Intervalls.

Bis heute gibt es nur eine Magnetresonanzdarstellung des *Ligamentum semicirculare humeri* (LSCH). Deshalb sollten detaillierte anatomische Studien und Beschreibungen des *Ligamentum semicirculare humeri* von frischen, unfixierten Schultern bei zeitgleicher Darstellung mit der Magnetresonanztomographie und mittels der Arthroskopie das Ziel dieser Arbeit sein.

An sechs von sieben Schultern war es möglich, mittels der Magnetresonanztomographie das *Ligamentum semicirculare humeri* vollständig oder in Teilen zu erkennen. Arthroskopien wurden an neun Schultergelenken durchgeführt und in allen Fällen konnte das Band von der Innenseite des Gelenks identifiziert werden. Die anatomischen Präparationen der konservierten Schultern stimmten mit den Ergebnissen der MRI– und arthroskopischen Untersuchungen exakt überein.

Das *Ligamentum semicirculare humeri* entspringt in zwei Anteilen auf der oberen Facette des *Tuberculum minus* und von der vorderen Facette des *Tuberculum majus* direkt über dem *Sulcus intertubercularis*.

Das Band verläuft dann in einem Bogen unter den Sehnen der *Mm. supraspinatus et infraspinatus*, um dann nach hinten im rechten Winkel unter die Sehnen abzubiegen. Der Ansatz des Bandes liegt auf der hinteren Facette des *Tuberculum majus* zwischen den Ansätzen der *Mm. infraspinatus et teres minor*.

Es wurde eine Einschätzung des Muskelzugs der Rotatorenmuskelmanschette auf das Schultergelenk durchgeführt und dabei die Rolle des LSCH auf die Art und den Grad des Zuges abgeschätzt. Unter Bezug auf die anatomischen Beobachtungen kann gefolgert werden, dass das LSCH die Y-Form des kompletten Risses beeinflusst und dass das Ausmass des Risses von der Belastung des LSCH durch den Muskelzug der *Mm. supraspinatus et infraspinatus* abhängt.

Der seitliche Teil des Rotatoren-Intervalls wird vom *Ligamentum glenohumerale superius* und vom *Ligamentum semicirculare humeri* gebildet. In diesem Bereich laufen sie im rechten Winkel zueinander, aber sie verwachsen nicht miteinander. Die beiden Bänder bilden gleichsam das Dach über dem *Sulcus intertubercularis* und stehen in engem Kontakt zum

Oberrand des *M. subscapularis*, der Vorderkante des *M. supraspinatus* und dem *Ligamentum transversum humeri*. Zusammen bilden sie einen Komplex, der die lange Bizepssehne im *Sulcus intertubercularis* hält und im weiteren Verlauf den intraartikulären Teil dieser Sehne bedeckt, um somit Luxationen dieses wichtigen aktiven Stabilisators des Schultergelenks zu verhindern.

7 Appendix of Figures

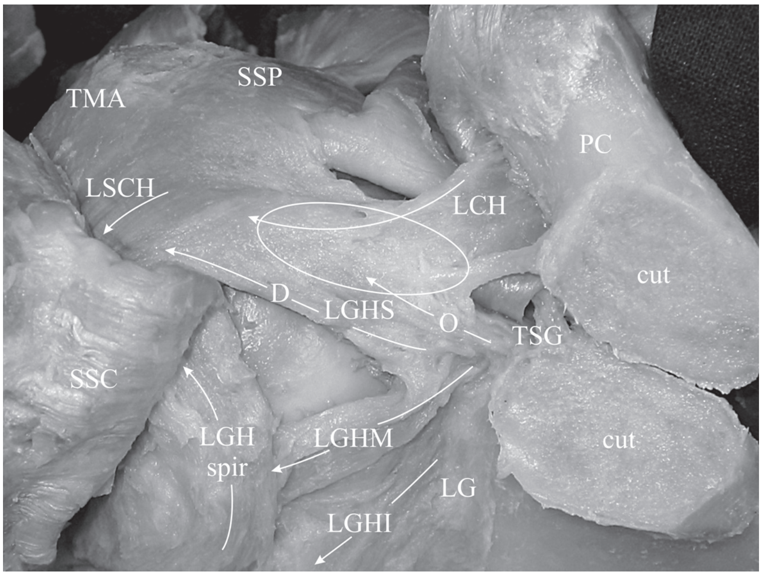


Figure 1
An anterior view of a fixed right shoulder joint specimen. The *Processus coracoideus* (PC) is cut at its base (cut) and posteriorly moved together with the *Ligamentum coracohumerale* (LCH). The *M. subscapularis* (SSC) is laterally lifted up to visualize the anterior capsule.

Before the detailed dissection, the *Ligamentum glenohumerale superius* (LGHS) and LCH are tightly connected with each other (oval). The connection between the LGHS and the *Ligamentum glenohumerale medium* (LGHM) is also clearly visible. D – direct fibers of the LGHS; O – oblique fibers of the LGHS; LSCH – anterior part of the *Ligamentum semicirculare humeri*; LGHI – *Ligamentum gleohumerale inferius*; LGHspir – *Ligamentum glenohumerale spirale*; LG – *Labrum glenoidale*; SSP – *M. supraspinatus*; TMA – *Tuberculum majus*; TSG – *Tuberculum supraglenoidale*.

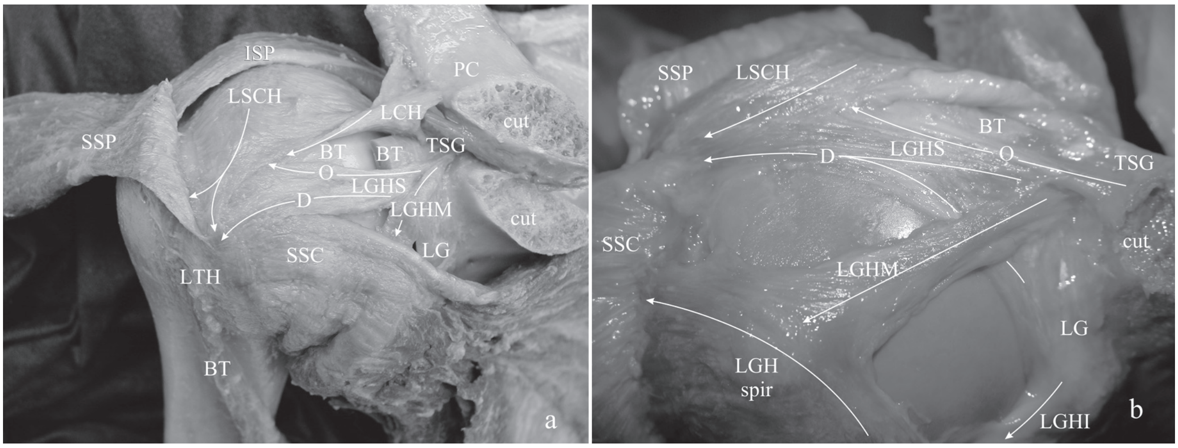


Figure 2
Anterior views of fixed (a) and not fixed (b) dissected right shoulder joint specimens. The *Processus coracoideus* (PC) is cut at its base (cut), the *Ligamentum coracohumerale* (LCH) is separated from the *Ligamentum glenohumerale superius* (LGHS) and posteriorly moved together with the *Processus coracoideus*. The ligamentous structures and "rotator cuff" muscles are finely dissected. The *Mm. supraspinatus* (SSP) *et subscapularis* (SSC) are separated from the shoulder joint capsule and placed laterally (on figure 2a only the *M. supraspinatus* is placed laterally).

The *Ligamentum glenohumerale superius* (LGHS) originates from anterio-superior labrum and has a loose connection to the *Ligamentum glenohumerale medium* (LGHM) at the origin region of the *Tuberculum supraglenoidale* (TSG). The oblique fibers of the LGHS (O) arise together with the LGHM from the *Tuberculum supraglenoidale* (TSG), run over the articluar part of the *Tendo capitis longi m. bicipitis brachii* (BT) and insert into the *Ligamentum semicirculare humeri* (LSCH). The direct fibers of the LGHS (D) arise beneath the oblique fibers from the *Labrum glenoidale* (LG) and run parallel to the *Tendo capitis longi m. bicipitis brachii* towards the *Tuberculum minus*. The *Ligamentum glenohumerale medium* arises at the *Tuberculum supraglenoidale* and inserts at the *Ligamentum glenohumerale spirale* (LGHspir).

a: An overview of the *Ligamentum glenohumerale superius* and its relation to the other ligaments and tendons of the shoulder joint in a fixed specimen. ISP – *M. infraspinatus*; LTH – *Ligamentum transversum humeri*.

b: An antero-superior view of the anatomy of the LGHS and its connections to neighboring structures on a fresh specimen. To tension the glenohumeral ligaments, the Humerus is externally rotated. LGHI – *Ligamentum glenohumerale inferius*.

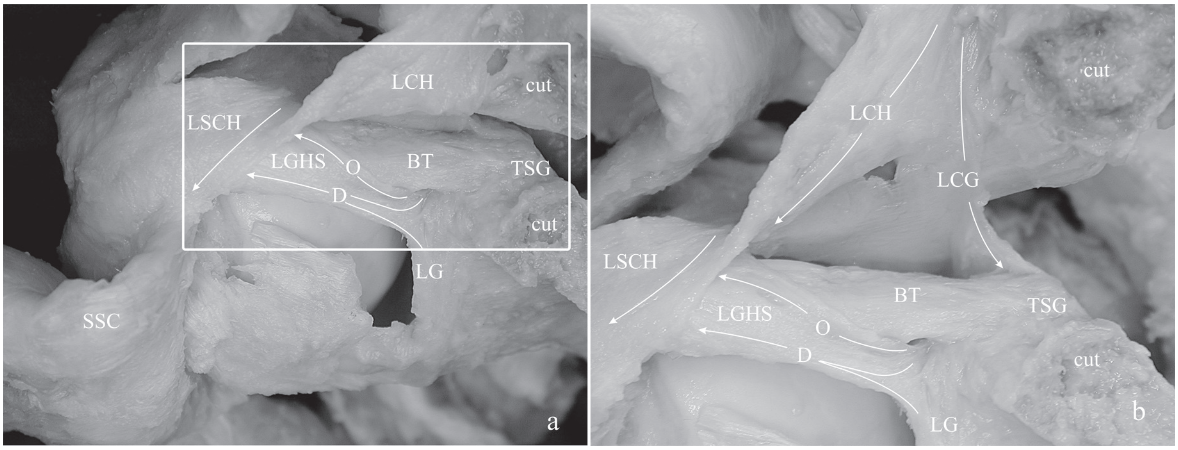


Figure 3
An anterior view of a fixed right shoulder joint specimen without the *Ligamentum glenohumerale medius*. The *Processus coracoideus* is cut at its base (cut) and moved backwards together with the *Ligamentae. coracohumerale* (LCH) and *coracoglenoidale* (LCG), the *M. subscapularis* (SSC) is placed laterally. In the case of an absence of the *Ligamentum glenohumerale medium*, the oblique (O) and direct (D) fibers of the *Ligamentum glenohumerale superius* (LGHS) arise from the *Labrum glenoidale* (LG).

a: BT – *Tendo capitis longi m. bicipitis brachii*; LSCH – *Ligamentum semicirculare humeri*; TSG – *Tuberculum supraglenoidale*.

b: A magnified view of the origins of the *Ligamentum glenohumerale superius* and the arrangement of the fibers. The *Ligamentae. corachumerale et coracoglenoidale* are placed under tension to achieve a better visualization of their relation to the underlying structures.

BT – *Tendo capitis longi m. bicipitis brachii*; LSCH – *Ligamentum semicirculare humeri*; TSG – *Tuberculum supraglenoidale*.

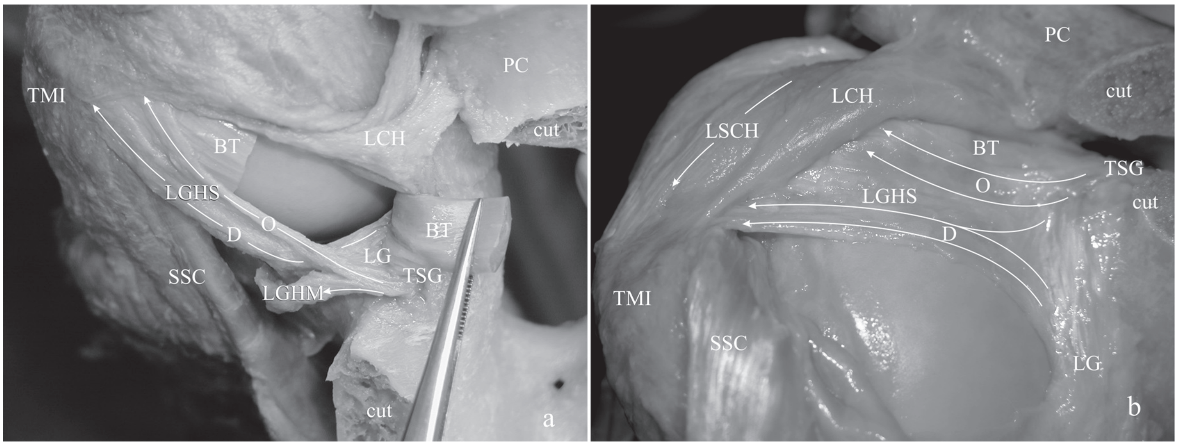


Figure 4
Antero-superior and anterior views of the detailed anatomy of the *Ligamentum glenohumerale superius* (LGHS) and the neighbouring structures on fixed (a) and not fixed (b) shoulder joint specimens. The *Processus coracoideus* (PC) is cut at its base (cut) and placed posteriorly together with the *Ligamentum coracohumerale* (LCH).

a: A superior view of the fixed right shoulder joint specimen. To visualize antero-superior direct fibers (D) of the *Ligamentum glenohumerale superius* (LGHS), the intraarticular portion of *Tendo capitis longi m. bicipitis brachii* (BT) is cut and lifted up with the forceps. The antero-superior direct fibers of the LGHS originate from the *Labrum glenoidale* (LG), arising from below the long head tendon of the biceps. The oblique fibers of the LGHS (O), together with the *Ligamentum glenohumerale medium* (LGHM), originate from the *Tuberculum supraglenoidale* (TSG).

TMI – *Tuberculum majus*; SSC – *M. subscapularis*.

b: An anterior view of the not fixed shoulder joint specimen after the *Ligamentum glenohumerale medium* from the *Tuberculum supraglenoidale* (TSG) have been removed. The point of origin of the anterior part of the direct fibers (D) of the *Ligamentum glenohumeale superius* (LGHS) on the anterior *Labrum glenoidale* (LG) is clearly visible. Above the direct fibers, the oblique fibers (O) of the LGHS run over the lateral part of the intraarticular portion of the *Tendo capitis longi m. biceps brachii* (BT). Laterally, the direct fibers run parallel to the *Tendo capitis longi m. bicipitis brachii* the *Tuberculum minus* (TMI). The insertion region of the LGHS is covered with the anterior fibers of the *Ligamentum semicirculare humeri* (LSCH).

SSC – *M. subscapularis*.

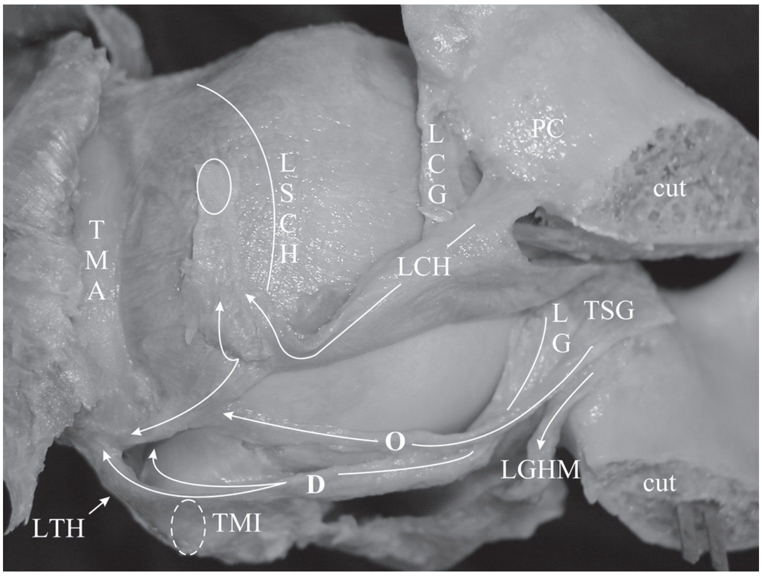


Figure 5
The detailed anatomy of the insertion region of the *Ligamentum glenohumerale superius* (LGHS).

To visualize the insertion region of the LGHS, the anterior, superficial fibers of the *Ligamentum semicirculare humeri* (LSCH) are removed (oval) from the *Tuberculum minus* (TMI, doted oval) and turned posteriorly together with the *Ligamentum coracohumerale* (LCH). The intraarticular part of the *Tendo capitis longi m. bicipitis brachii* is removed. The direct fibers (D) of the LGHS insert into the bottom of the *Sulcus intertubercularis* and overbridge the *Sulcus intertubercularis*, forming the superior part of the *Ligamentum transversum humeri* (LTH). The oblique fibers (O) of the LGHS orginate from *Tuberculum supraglenoidale* (TSG) and insert into the *Ligamentum semicirculare humeri* (LSCH).

LGHM – *Ligamentum glenohumerale medium*; LCG - *Ligamentum coracoglenoidale*; PC, cut - *Processus coracoideus* cut at its base; TMA – *Tuberculum majus*; LG – *Labrum glenoidale*.

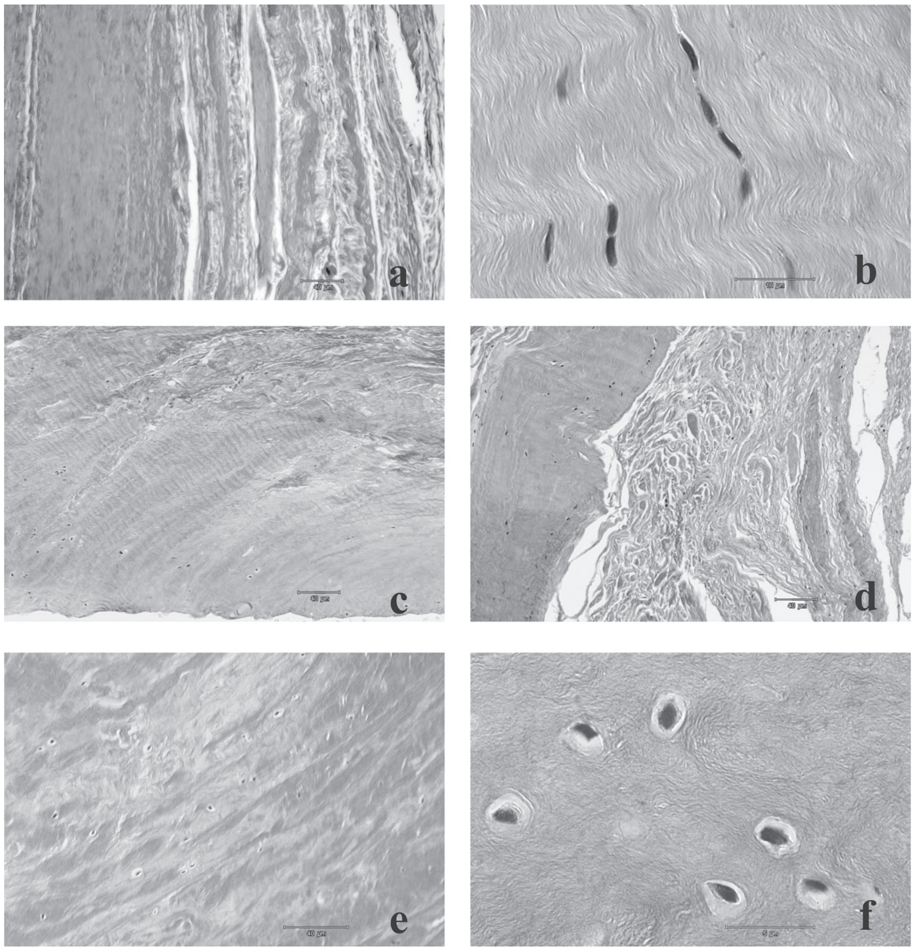


Figure 6
A light, microscopic investigation of the different parts of the *Ligamentum glenohumerale superius* (LGHS). The LGHS is divided into the main middle part, the origin and the insertion regions.

a, b: Middle part of the LGHS.

a: An overview of the collagen fiber arrangement at low magnification. The collagen fibers are lying in parallel bundles of collagen fibers, which are separated from each other by relatively wide spaces of loose connective tissue at some regions. Magnification bar is 40 µm

b: An overview of the middle part of the LGHS at high magnification. The cells surrounded by the collagen fibers are typical fibrocytes, lying between the parallelly-oriented collagen fibers individually, in pairs or in rows. Magnification bar is 10 µm

c, d: A light microscopic overview of the origin and insertion regions of the LGHS at low magnification.

c: At the origin of the labrum glenoidale, the arising collagen fibers are partly masked by the exrtracellular matrix, showing the tissue properties of fibrocartilage. Magnification bar is 40 µm

d: At the region where it inserts into the *Sulcus intertubercularis* the structure of the LGHS comes to have the features of fibrocartilagineous tissue, which is remarkably different from the less organized structure of the joint capsule. Magnification bar is 40 µm

e, f: The cells of the LGHS at the origin and insertion regions.

The fibrocartilagineous parts of the ligament are populated with oval, chondrocyte-like cells. Magnification bars are 40 and 5 µm

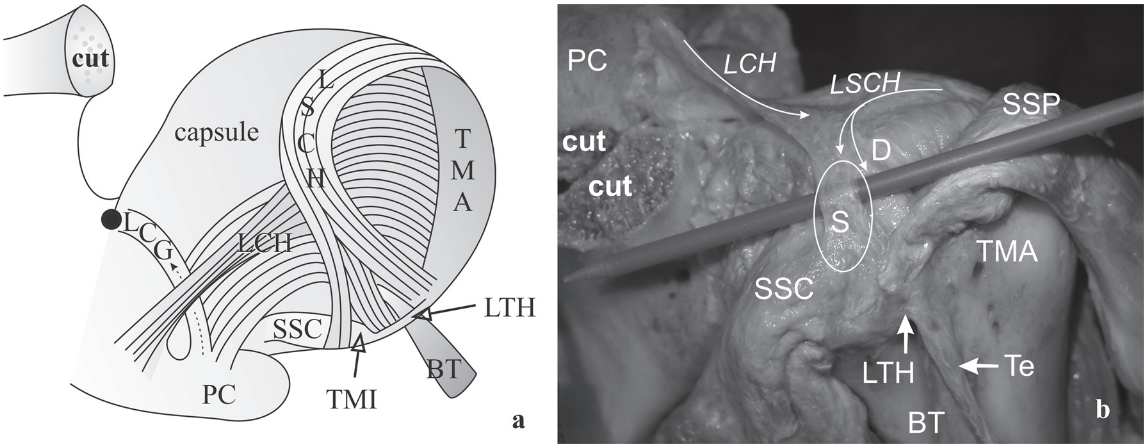


Figure 7
a: Schematic drawing of the superior capsular ligaments.

LSCH – *Ligamentum semicirculare humeri*; LCH – *Ligamentum coracohumerale*; LCG – *Ligamentum coracoglenoidale*; capsule – Glenohumeral joint capsule; cut – acromial base; PC – *Processus coracoideus*; TMA – *Tuberculum majus*; TMI – *Tuberculum minus*; SSC – *M. subscapularis*; BT – *Tendo capitis longi m. bicipitis brachii*; Filled ring – *Tuberculum supraglenoidale*.

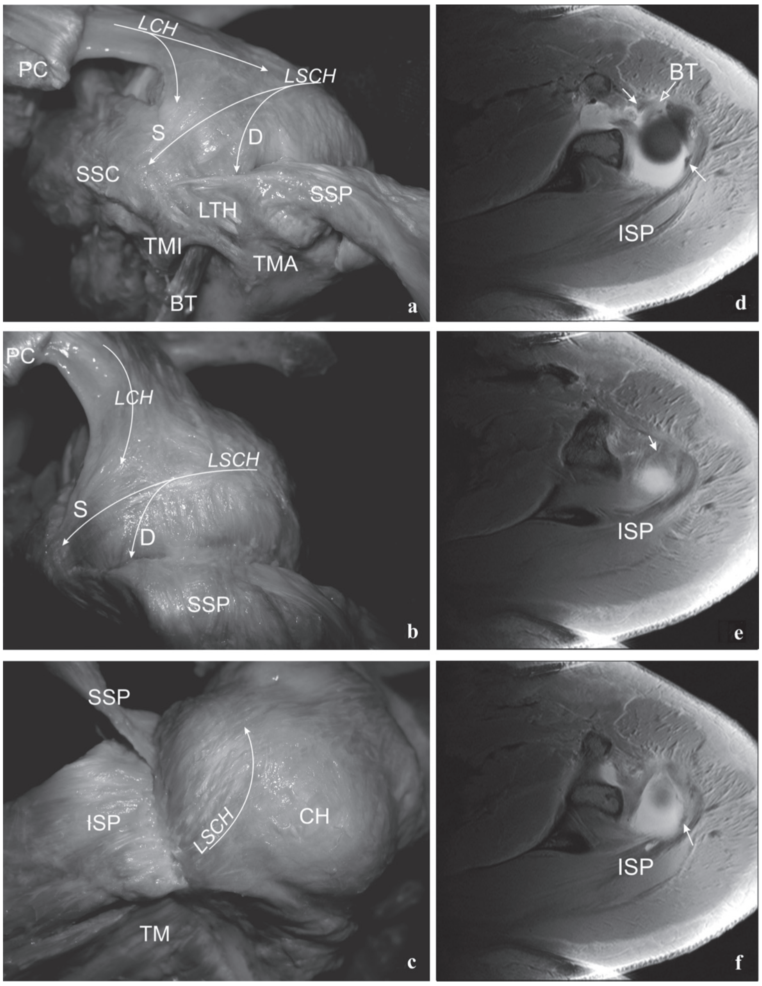
b: An anterior view of a dissected left shoulder joint.

The *Acromion* is cut from the *Spina scapulae* and removed together with the *Ligamentum coracoacromiale*. The *M. supraspinatus* tendon (SSP) is separated from the shoulder joint capsule and placed laterally. The *Processus coracoideus* (PC) is cut at its base (cut) and moved posteriorly, together with the *Ligamentum coracohumerale* (LCH), to provide a better visualization of the superior capsular structures.

At its insertion into the joint capsule, the SSP tendon follows the course of the *Ligamentum semicirculare humeri* (LSCH). The LSCH divides into superficial-medial (S, separated from the underlying joint capsule by a plastic probe) and deep-lateral (D) fiber layers. The superficial-medial layer inserts into the *Tuberculum minus* and the deep-lateral layer on the *Tuberculum majus* (TMA). At the insertion region on the *Tuberculum minus*, the superficial-medial layer interweaves with the *Ligamentum transversum humeri* (LTH) and the *M. subscapularis* tendon (SSC). The LCH inserts into the LSCH.

BT - *Tendo capitis longi m. bicipitis brachii*; Te - cranial prolongation of the *Tendo m. pectoralis major* overlaying the *Tendo capitis longi m. bicipitis brachii*.

Figure 8
A gross anatomical specimen of a dissected left shoulder joint and the corresponding MR arthrograms. The *Mm. supra-, infraspinatus et M. teres minor* have been removed from the joint capsule and placed laterally. The underlying capsular structures are visualized.



a: An antero-lateral view of the dissected shoulder joint specimen. The *Ligamentum coracohumerale* (LCH) fuses with the *Ligamentum semicirculare humeri* (LSCH). The superficial-medial layer (S) of the LSCH is closely related to the *M. subscapularis* tendon (SSC), *Ligamentum transversum humeri* (LTH) and the part of the *M. supraspinatus* tendon (SSP) that inserts into the *Tuberculum minus* (TMI) of the *Humerus*. The deep-lateral layer (D) of the LSCH inserts together with the SSP tendon into the anterior facet of the *Tuberculum majus* (TMA).

b: A latero-superior view of the dissected shoulder joint specimen. The *Ligamentum coracohumerale* (LCH) fuses with the *Ligamentum semicirculare humeri* (LSCH). The course of the LSCH is perpendicular to the longitudinal axis of the *M. supraspinatus* (SSP) tendon.

c: A postero-lateral view of the dissected shoulder joint specimen. The *Ligamentum semicirculare humeri* (LSCH) inserts into the posterior facet of the *Tuberculum majus* between the *Mm. infraspinatus et teres minor* tendons.

PC - *Processus coracoideus*; BT - *Tendo capitis longi m. bicipitis brachii*; CH - *Caput humeri*; TM - *M. teres minor*: ISP - *M. infraspinatus*.

d - f: MR arthrograms of the same left shoulder specimen (axial T1 WI).

d, f: Anterior and posterior parts of the *Ligamentum semicirculare humeri* (white arrows) are visible as hypotensive stripes under the *M. infraspinatus tendon* (ISP) and in front of the *Tendo capitis longi m. bicipitis brachii* (white unfilled arrow, BT).

e: The middle part of the *Ligamentum semicirculare humeri* (white arrow) is visible as an anatomic structure with an intermediate signal, coursing perpendicularly to the *Mm. supraspinatus et infraspinatus* longitudinal axis. ISP - *M. infraspinatus*.

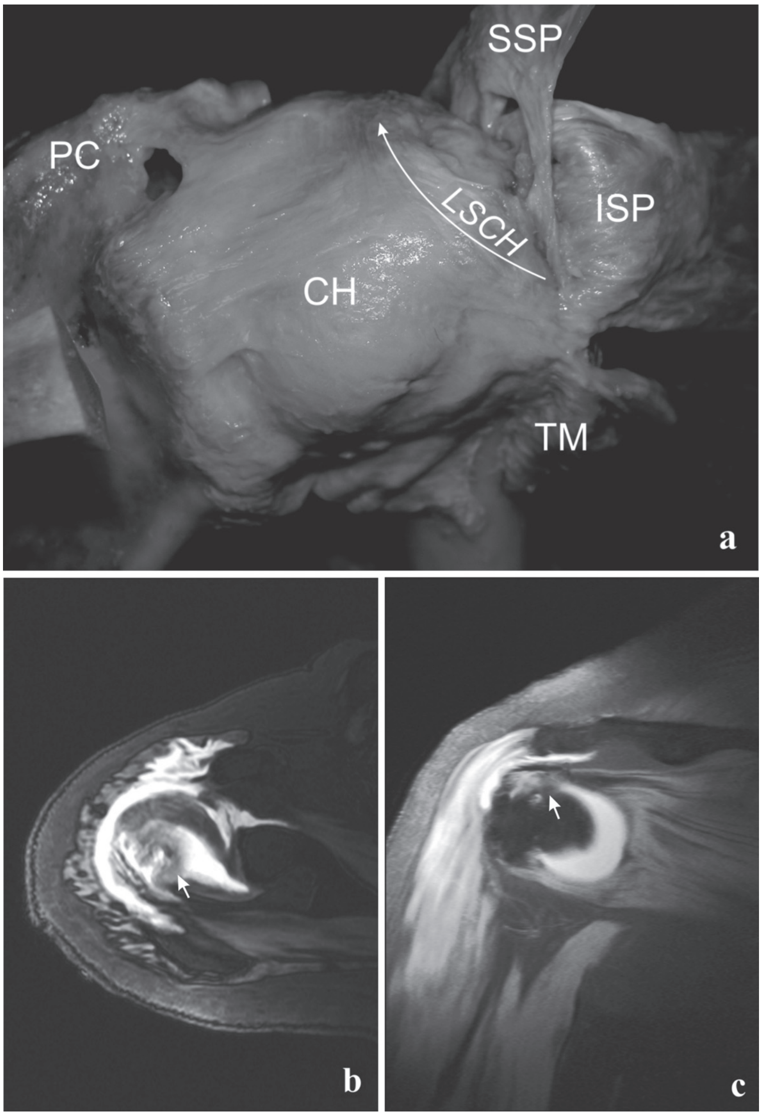


Figure 9
a: A posterio-superior view of a dissected right shoulder joint with the full-thickness tear of the *M. supraspinatus* tendon. The rotator cuff muscles are dissected from the joint capsule and placed laterally; the *M. supraspinatus* tendon is lifted upwards.

The *Ligamentum semicirculare humeri* (LSCH) is located more medially than in the specimens without rotator cuff tears. The shape of the rupture in the *M. supraspinatus* (SSP) tendon fits the course of the LSCH. Lateral from the LSCH, there is a defect in the capsule (white unfilled arrow) that is surrounded by the LSCH and the Y-shaped remnant of the ruptured SSP.

TM - *M. teres minor*; CH - *Caput humeri*; PC - *Processus coracoideus*.

b, c: MR arthrograms of the same right shoulder joint specimen with the rotator cuff tear (axial DESS and oblique coronal PD-WI). The thickening, interpreted as the *Ligamentum semicirculare humeri*, is indicated with the white arrow. The capsular tissue defect (white unfilled arrow) is visible lateral to the LSCH.

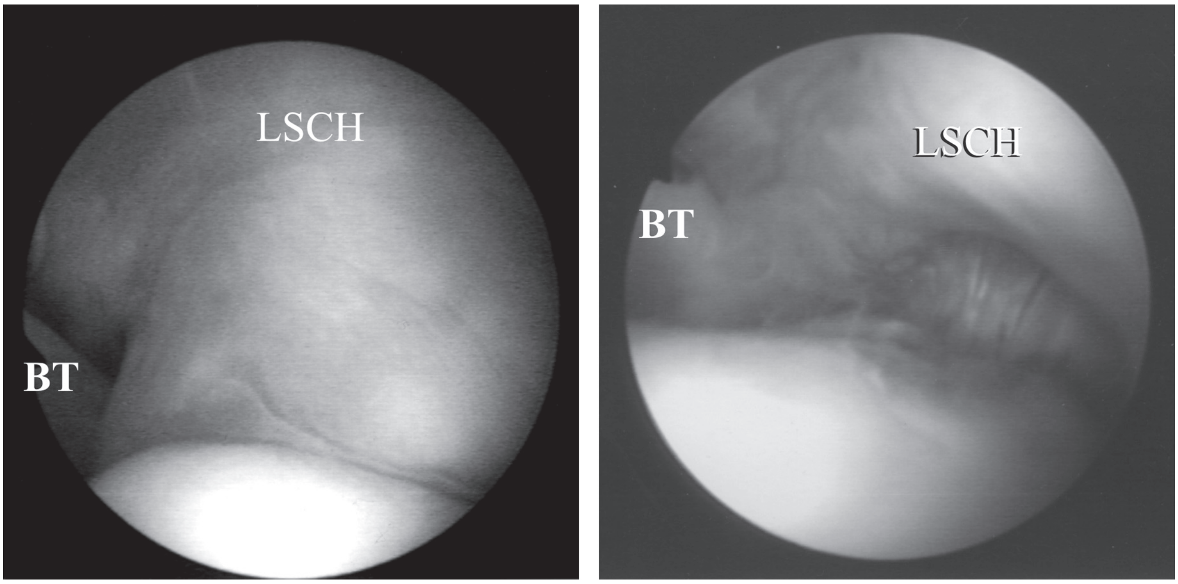


Figure 10
An arthroscopic view of the right shoulder joint through the posterior portal with the 30 degree arthroscopic optics. A supero-lateral view of the joint space.

a: A right joint without rotator cuff pathology. Biceps tendon, humeral head and a capsular structure with bowed course from posterior to anterior, the *Ligamentum semicirculare humeri* are visible. The cleavage of the LSCH is visible anteriorly: The LSCH fibers run around the biceps tendon, surrounding the intraarticular part of the tendon anteriorly and posteriorly at its entrance into the joint.

b: A right glenohumeral joint with a M. supraspinatus tear. The defect is medially bordered by pathologically changed, arched, inflammatory tissue. The course of the arched structure is similar to the course of the LSCH in the joint without pathological changes.

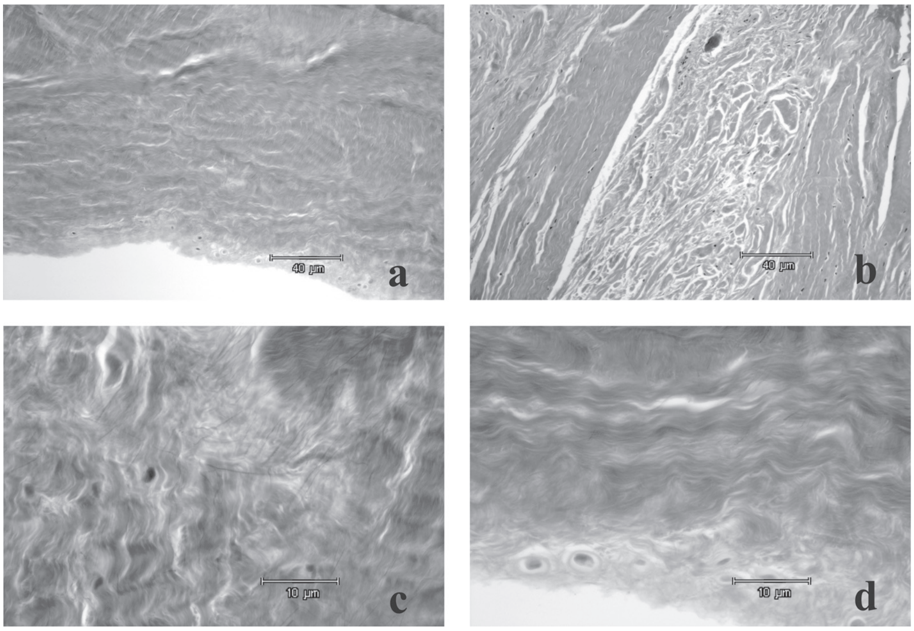


Figure 11
A light microscopic investigation of the *Ligamentum semicirculare humeri*(LSCH).

a, b: An overview of the collagen fiber arrangement at low magnification.

The sections are in parallel (a) and perpendicularly (b) to the longitudinal axis of the LSCH.

a: The collagen fibers of the LSCH lie as parallel bundles, crossing the perpendicularly-oriented fibers of the *M. supraspinatus* tendon. On the inferior, intra-articular side of the ligament, cartilage-like chondroid cells and fibrocartilage-like tissue build up a gliding surface of the ligament. Magnification bar is 40 µm

b: The parallelly-oriented bundles of collagen fibers of the LSCH are entangled with the *M. supraspinatus* tendon fibers, which run perpendicular to the longitudinal axis of the LSCH. Magnification bar is 40 µm

c, d: Light microscopic views of the regions where the fibers from the muscle tendons of the rotator cuff are fused with the LSCH (c) and of the gliding surface of the intra-articular side of the ligament (d) at high magnification.

c: The arrangement of the collagen fibers at the region where the fibers of the rotator cuff muscles fuse into the LSCH. In this region, the dense connective tissue is rich in elastic fibers. Magnification bar is 10 µm
d: The oval, chondrocyte-like cells of the LSCH lie within the fibrocartilage tissue that forms the gliding surface of the intra-articular side of the ligament. Magnification bar is 10 µm

8 References

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List of Publications

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Kask K, Busch LC. Kolts I.
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Anatomy of the superior and middle glenohumeral ligaments in association with the SLAP-lesion
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