



**ANATOMY AND CLINICAL RELEVANCE  
OF THE GLENOHUMERAL  
JOINT CAPSULE AND LIGAMENTS**

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## LIST OF ORIGINAL PUBLICATIONS

The PhD dissertation includes the following articles referred to in the text by Roman numerals:

- I. I. Kolts, LC. Busch, A. Arend, A. Eller, M. Merila, M. Russlies. Anatomy of the coracohumeral and coracoglenoidal ligaments. *Annals of Anatomy* 2000; 182: 563–566.
- II. I. Kolts, LC. Busch, H. Tomusk, A. Raudheiding, A. Eller, M. Merila, M. Pääsuke, T. Leibecke, W. Kühnel. Macroscopical anatomy of the so-called “rotator interval”. A cadaver study on 19 shoulder joints. *Annals of Anatomy* 2002;184: 9–14.
- III. M. Merila, T. Leibecke, H-B. Gehl, L-C. Busch, M. Russlies, A. Eller, T. Haviko, I. Kolts. The anterior glenohumeral joint capsule: macroscopic and MRI anatomy of the *fasciculus obliquus* or so-called *Ligamentum glenohumerale spirale*. *European Radiology* 2004;14: 1421–1426.
- IV. M. Merila, H. Heliö, L. C. Busch, H. Tomusk, E. Poldoja, A. Eller, T. Haviko, I. Kolts. Extra- and intra-articular anatomy of the *fasciculus obliquus* or so-called *Ligamentum glenohumerale spirale*. *Arthroscopy* 2005 (submitted).

## ABBREVIATIONS

AIGHL	anterior band of the inferior glenohumeral ligament
AxIGHL	axillar part of the inferior glenohumeral ligament
IGHL	inferior glenohumeral ligament
CAL	coracoacromial ligament
CGL	coracoglenoidal ligament
CHL	coracohumeral ligament
DESS 3D	dual echo steady state three dimensional
PIGHL	posterior band of the inferior glenohumeral ligament
GHJ	glenohumeral joint
LHB	tendon of the long head of the biceps brachii muscle
LHT	tendon of the long head of the triceps brachii muscle
M	matrix
MGHL	medial glenohumeral ligament
MR	magnetic resonance
MRI	magnetic resonance imaging
NA	number of acquisitions
PD WI	proton density weighted imaging
RC	rotator cable
RI	rotator interval
SCL	semicircular ligament
SGHL	superior glenohumeral ligament
SL	slice thickness
spiral GHL	spiral glenohumeral ligament
TE	echo time
THL	transverse humeral ligament
TR	repetition time
WI	weighted imaging

## INTRODUCTION

The glenohumeral joint (GHJ) presents a unique anatomical design which ensures the largest range of motion among all joints of the human body. Its outstanding mobility is based on minimally constrained bony articulation between the glenoid of the scapula and humeral head with high cartilage surface area disparity (Soslowsky *et al.*,1992). Since a limited bony support, the GHJ has a delicate balance between mobility and stability.

The stability of the GHJ is primarily maintained by the surrounding soft tissues, mainly the glenohumeral ligaments and rotator cuff muscles. The glenohumeral ligaments are static stabilizers for the humeral head in extremes of shoulder motion, while the rotator cuff muscles provide dynamic compression and centering of the humeral head into the glenoid of the scapula (Turkel *et al.*, 1981; Cain *et al.*,1987; O'Connell *et al.*,1990; O'Brien *et al.*,1995; Wuelker *et al.*,1998).

Because of this particular functional anatomy, the GHJ is vulnerable to shoulder overuse injuries and traumas. In fact, a dislocation of the shoulder was the first orthopaedic case reported in a patient with epilepsy 2000 years before the time of Hippocrates (O'Brien *et al.*,1995). The shoulder was one of the first areas for which chronic overuse lesions were described (Meyer, 1937).

In current orthopaedic practice, the GHJ is the most commonly dislocated joint accounting for 50% of all joint dislocations in the human body.

The diagnosis and treatment of the GHJ pathology is based on its anatomy.

Fundamental knowledge of the normal anatomy is essential for recognizing pathologic conditions in the clinical interpretation of diagnostic magnetic resonance images (MRI) and during surgical procedures of the shoulder joint.

The literature gives considerable attention to the anatomy of the GHJ in association with different shoulder problems, such as an unstable shoulder or rotator cuff injuries. Despite this, clinical experience and shortcomings of the contemporary diagnostics and treatment methods have revealed the need for more detailed anatomical knowledge about clinically significant capsular regions of the GHJ.

The variety of opinions and remaining gaps within these capsular areas inspired this anatomic investigation to improve our understanding of the GHJ anatomy and to provide a basis for further biomechanical, diagnostic and clinical studies.



# REVIEW OF THE LITERATURE

## 1. Gross anatomy and function of the GHJ

To understand the anatomical arrangement and clinical importance of the capsuloligamentous complex in the GHJ, it is appropriate to describe the comprehensive gross anatomy and basic function of the GHJ.

The synovial GHJ is composed of the large spherical head of the humerus which articulates against the small and shallow “pear-shaped” glenoid fossa of the scapula.

All the three types of motion — sliding, spinning and rolling — occur at glenohumeral articulation during different motions of the arm. The most important function of the shoulder — arm elevation — is coordinated by the so-called scapulohumeral rhythm (Inman *et al.*, 1944) indicating that the ratio of GHJ to scapulothoracic motion throughout the entire arc of elevation is about 2 : 1.

The humeral head has an articular surface that is three times as large as that of the glenoid. In any position of rotation, only 25%–30% of the humeral head is in contact with the glenoid surface (Cole and Warner 1999). The relative lack of the depth and surface area of the glenoid is partially compensated by the fibrous labrum, which deepens the glenoid cavity approximately 50% (Howell and Galinat 1989). In addition, the labrum serves as the attachment site for the joint capsule, ligaments and the long head of the biceps brachii tendon, connecting them to the bone, periosteum and articular cartilage of the glenoid.

These facts emphasize the importance of the soft tissues surrounding the GHJ to provide stability during shoulder function between the minimally constrained articular surfaces.

The concept of grouping soft tissue structures into supporting layers of the GHJ was introduced by Cooper *et al.* (1993), which aids the surgeon to identify different tissue planes and allows atraumatic dissection.

The first layer encountered after dissection through the skin and subcutaneous fat is composed of the deltoid and pectoralis major muscle bellies with their overlying fascia and the enveloping epimysium. The deltoid muscle is a strong elevator and abductor of the arm, especially above 90° (Shevlin *et al.*, 1969). The pectoralis major is a powerful adductor of the GHJ and is active in internal rotation.

Anteriorly, the second layer consists of the clavipectoral fascia, the conjoined tendon of the short head of the biceps and coracobrachialis, and the coracoacromial ligament. Posteriorly, the dense posterior scapular fascia overlies the infraspinatus and teres minor muscles. The superior and lateral regions are covered by the superficial layer of the subacromial and subdeltoid bursa.

The third layer includes the deep part of the subdeltoid and subacromial bursa and the underlying four muscles that form the rotator cuff — subscapularis, supraspinatus, infraspinatus and teres minor muscles. The rotator cuff takes their origin from the body of the scapula and envelopes the humeral head

as they insert along the tuberosities of the proximal humerus. The musculotendinous cuff is firmly attached to the underlying glenohumeral capsule and provides circumferential reinforcement, except at the rotator interval superiorly (between the supraspinatus and subscapularis muscle) and axillary recess inferiorly (between the teres minor and the subscapularis muscle). These two regions represent defects in layer 3 through which layer 4 protrudes (Sher 1999).

The subscapularis muscle functions as the internal rotator and contributes to arm abduction. The supraspinatus muscle assists the deltoid in arm abduction. The infraspinatus and the teres minor muscles rotate the humerus externally (Sher 1999).

The deepest fourth layer is the capsule and glenohumeral ligaments of the GHJ.

In addition to these anatomic layers, the long head of the biceps brachii tendon originates from the labrum and supraglenoid tubercle, runs obliquely over the humeral head inside the GHJ and continues outside it in the intertubercular groove of the proximal humerus. Based on its anatomic position, it serves as a superior checkrein to excursion of the humeral head. In abduction and external rotation of the arm, it helps to stabilize the GHJ anteriorly together with the anterior capsular ligaments (Burkhead *et al.*, 1999).

The unique feature of the GHJ to maintain the humeral head precisely in the centre of the glenoid and at the same time allow a vast range of motion is achieved by a combination of dynamic and static mechanisms (Soslowsky *et al.*, 1992).

The main dynamic stabilizers are the rotator cuff muscles and the tendon of the long head of the biceps brachii muscle (LHB). These structures contribute to the dynamic stabilization of the GHJ through two important mechanisms:

1. Joint compression, resulting from synchronous active muscle contraction, keeps the articular surfaces congruent in different arm positions. At the same time these muscles depress the humeral head forming a fulcrum that allows the deltoid to elevate the arm.
2. Dynamization of the glenohumeral ligaments through direct attachments to the rotator cuff tendons adjacent to the humeral tuberosities.

The dynamic shoulder model developed by Warner *et al.*(1993) demonstrated that ligament orientation is indeed affected by rotator cuff contraction. Augmentations of these dynamic mechanisms are balanced scapulothoracic rhythm, coordinated function of the scapular rotator muscles and proprioception (Cole and Warner 1999).

The most important static mechanism is provided by stabilizing capsule and ligaments of the GHJ. The other components that help maintain stability are specific geometry of the GHJ articular surfaces, glenoid labrum, negative intra-articular pressure during humeral head translation and adhesion-cohesion effect of the joint fluid. Passive tension within the rotator cuff structures has also some concomitant static role in preventing glenohumeral translation (Cole and Warner 1999).

## 2. Capsule and ligaments of the GHJ

### 2.1. Gross anatomy and biomechanics

The GHJ capsule is large with a surface twice as large as that of the humeral head. Normal joint capacity is approximately 10–30 ml of fluid (Reeves 1966; O'Brien *et al.* 1999; Cuomo *et al.*, 1999).

The key elements of the capsule are the glenohumeral ligaments, which were first mentioned by the Greek-Roman physician Galen in the second century AD (Jobe 1999).

According to the currently accepted opinion, the glenohumeral ligaments are the most constant and discreet thickenings of the joint capsule, which have considerable variability in size, shape and attachment sites (O'Brien *et al.*, 1999).

In contrast to hinge-like joints, such as the knee where the ligaments remain isometric during joint motion, the glenohumeral ligaments must be slack in most of the joint's positions for the wide arc of movements. They are important stabilizers in extreme amplitudes of the GHJ motion. The function of the glenohumeral ligaments depends on the shoulder position and the directions of applied forces (Matsen *et al.*, 1999). According to the principles of biomechanics, orientation of the fibres in ligaments reveals the direction of the tensile stresses that they have to resist (Carlstedt *et al.*, 1989).

Biomechanical investigations focused on the contribution of the glenohumeral ligaments in GHJ stability began with the most cited study of Turkel *et al.*, in 1981. Since then, studies of selective or subsequent glenohumeral ligament cutting (Ovesen and Nielsen 1985; Warner *et al.*, 1992; Blasier *et al.*, 1992; Harryman *et al.*, 1992; Branch *et al.*, 1995; O'Brien *et al.*, 1995) have helped to assess their functional importance. Criticism of these studies as being allegedly nondynamic led to further investigations, which used strain gauge analysis (Weber and Caspari 1989; O'Connell *et al.*, 1990; Terry *et al.*, 1991; Bigliani *et al.*, 1992; Boardman *et al.*, 1996; McMahon *et al.*, 1999; Pollock *et al.*, 2000; Urayama *et al.*, 2001). Interestingly, these dynamic studies mainly confirmed the results of the previous studies documenting the contribution of the glenohumeral ligaments to the shoulder stability.

Innervation of the GHJ capsule and ligaments originates from C4–C7 nerve roots. Their scapular side receives branches from the axillary nerve and the musculocutaneous nerve. The middle anterior portion is supplied by the subscapular nerve. The inferior, anterior and posterior capsules are supplied by the axillary nerve. The humeral side of the capsule is innervated by the same nerves, except the subscapular nerve (Gardner 1948). The neural end organs of these nerves are Pacinian corpuscles, Ruffini's end organs, and free nerve endings within the collagenous ligaments and surrounding connective tissue (Vangsnæs *et al.*, 1995; Steinbeck *et al.*, 2003).

For vascular supply, the axillar artery supplies the GHJ capsule and ligaments with several branches. The lateral portion of the capsuloligamentous complex is supplied by the anterior and posterior circumflex arteries. The medial aspect of the capsule and ligaments is vascularized by the suprascapular, circumflex scapular, and periosteal arteries (Andary *et al.*, 2002).

Contemporary textbooks and atlases of anatomy do not present the detailed anatomy of these GHJ ligaments (Agur 1991; Moore 1992; Tillmann and Töndury 1987; Platzer 1992). In the official Terminologia Anatomica 1998, only three terms — the coracohumeral ligament (CHL), the transverse humeral ligament and glenohumeral ligaments — are noted. Despite this, the clinical literature devotes great attention to the capsuloligamentous complex of the GHJ. Clinical observations by orthopaedic surgeons (Moseley and Overgaard 1962; Neer and Foster 1980; Rowe *et al.*, 1978; Williams *et al.*, 1994), cadaveric shoulder dissections (Flood 1829; Schlemm 1853; Delorme 1910; Depalma 1949; Landsmeer and Meyers 1959; Moseley et Overgaard 1962; Turkel *et al.*, 1981; Ferrari 1990; O'Brien *et al.*, 1990; Clark *et al.*, 1990; Clark *et al.*, 1992; Steinbeck *et al.*, 1998; Kolts *et al.*, 2001; Ide *et al.*, 2004) as well as morphological investigations (Weitbrecht 1969; O'Brien *et al.*, 1990; Clark *et al.*, 1990; Gohlke *et al.*, 1994; Kolts *et al.*, 2000) have markedly improved the current anatomical understanding of these structures.

### **2.1.1. Transverse humeral ligament (THL)**

The THL consists of a few collagen fibers of the capsule that extend between the greater and lesser tuberosities of the humerus. It is often weak or absent or is present lower down in the bicipital groove (Yamaguchi and Bindra 1999).

Although the THL helps to stabilize the LHB in its sulcus, most authors agree that the THL does not play an important role in retaining the LHB in its bony groove (Abbot and Saunders 1939; Petersson 1986; Habermeyer and Walch 1996).

### **2.1.2. Coracohumeral (CHL) and coracoglenoidal (CGL) ligaments**

The CHL is constant ligament with a width of 1 to 2 cm within the anterior superior GHJ capsule. The descriptions of the origin, structure and insertion of the coracohumeral ligament vary in textbooks of anatomy (Tillmann and Töndury 1987; Agur 1991; Platzer 1992; Moore 1992; Soames 1995) and in the clinical literature (Clark *et al.*, 1990; Edelson *et al.*, 1991; Clark and Harryman 1992; Harryman *et al.*, 1992; Neer *et al.*, 1992; Birnbaum and Lierse 1992; Cooper *et al.*, 1993; Boardman *et al.*, 1996). The most widespread opinion is that the CHL arises from the base and the posterior surface of the coracoid process as an extra-articular structure, runs laterally and blends with the upper

parallel fibres of the SGHL before its insertion in the greater and lesser tubercles of the humerus. Cooper *et al.* (1993) found that the CHL is an extra- as well as intraarticular structure. It is divided into two major bands, one of which inserts into the anterior edge of the supraspinatus tendon and the greater tuberosity and other into the superior border of the subscapularis tendon, the THL and the lesser tuberosity. The fibres within these insertional regions are indistinguishable from those of the capsule. Weinstabl *et al.* (1986) believed that the CHL can be partly built of the strong fibers of the M. pectoralis minor tendon.

Despite different opinions in the literature, the current consensus is that the CHL together with the tightly connected SGHL constrains the humeral head on the glenoid, limits inferior translation and external rotation when the arm is adducted, and posterior translation when the shoulder is in a position of forward flexion, adduction, and internal rotation. Also, these ligaments make up an important stabilizing ligamentous sling for the intraarticular part of the LHB (Yamaguchi and Bindra 1999).

Macalister (1867) and Sappey (1867) described independently for the first time the ligamentous band as a remnant of the M. pectoralis minor tendon (Macalister 1867) or a deep layer of the coracohumeral ligament (Sappey 1867). In the contemporary study by Weinstabl *et al.* (1986) the strong band of dense connective tissue was named the Lig. coracoglenoidale (CGL) which divided the CHL into two separate parts in 6% of cases. He also found strong association between the origin of the CHL and CGL in all investigated shoulder joints.

The CGL is not officially recognized in the Terminologia Anatomica. The clinical importance of the CGL has not yet been investigated.

### **2.1.3. Rotator cable or “transverse band”**

A bundle of capsular fibres within the superior capsule, running perpendicular to the rotator cuff tendons or “transverse band”, was first described as a deep extension of the CHL (Clark *et al.*, 1990; Clark and Harryman 1992). Burkhart and colleagues (1993) referred to this structure as the “rotator cable” (RC), which was found in all cases spanning the supraspinatus and infraspinatus tendon insertions.

They proposed a biomechanical model of the rotator cuff tear where the RC acts as a loaded cable of the suspension bridge. This concept was supported by a further biomechanical study (Halder *et al.*, 2002) indicating that maintenance or repair of this structure could be sufficient to restore shoulder function.

#### **2.1.4. Superior glenohumeral ligament (SGHL)**

The SGHL is the most constant ligament of the anterior GHJ capsule. It is present in over 90% of cases (DePalma *et al.*, 1949; Moseley et Overgaard 1962; O'Brien *et al.*, 1990; Yeh *et al.*, 1998; Steinbeck *et al.*, 1998; Kolts *et al.*, 2001).

In a classical cadaver study by DePalma *et al.*, (1949) three types of the glenoid attachment of the SGHL were found. It was attached to the MGHL, the biceps tendon, and the superior labrum in 76% of specimens. In 21% of cases it was attached to the biceps tendon and to the superior labrum, and in 1% of cases to the biceps tendon only. The SGHL runs superiorly and anteriorly around the biceps tendon. Laterally, it fuses with CHL and inserts into the fovea capitis of the humerus on the medial ridge of the intertubercular groove (Depalma *et al.*, 1949; Ferrari 1990; Kolts *et al.*, 2001). Werner *et al.*, (2000) was able to differentiate between two insertion variations of the SGHL, one into the posterior part of the bicipital groove and second, on to the anterior edge of the entrance to the groove.

Because of remarkable disparity of the SGHL and CHL regarding size and intimate position, Schlemm (1853) recognized it as the deep portion of the CHL. DePalma believed that this disparity and variable intra-articular visibility on dissected shoulders could be due to the embryologic development of the ligament from an extracapsular to an intracapsular position.

From the functional point of view, the SGHL alone plays a minor role in the stability of the GHJ and its biomechanical properties are described together with the close and parallel CHL (Yamaguchi and Bindra 1999). Nevertheless, the SGHL is an important component of the so-called “rotator interval”.

#### **2.1.5. Rotator interval (RI)**

The term “rotator interval” was first used by the orthopaedic surgeon Neer in 1970 (Fitzpatrick *et al.*, 2003). Being officially not recognized in the Terminologia Anatomica (1998), it is neither described in the classical textbooks and atlases of anatomy (Tillman and Töndury 1987; Platzer 1992; Agur 1991; Moore 1992; Soames 1995). In the clinical literature the RI has two different meanings depending on clinical findings. In association with ruptures of the rotator cuff, it is the tendinous connection between the supraspinatus and the subscapularis muscle. In conjunction with glenohumeral instability, it is defined as the triangular space of the GHJ capsule between the anterior portion of the supraspinatus tendon and the superior border of the subscapularis tendon (Gartsman *et al.*, 1999). The width of this capsular area is the largest at the base of the coracoid and its apex at the THL (Field *et al.*, 1995).

This distinct capsular area is controversially described as the weakest region without reinforcing structures (Steiner and Herman 1989), or as the thickest portion of the shoulder joint capsule (Jost *et al.*, 2000). Based on the observations

of the fetal and adult shoulder specimens, Cole *et al.*, (2001) suggested that the RI capsule may be congenitally deficient. The most detailed anatomic study (Jost *et al.*, 2000) revealed the medial RI with two layers and lateral the RI with four different layers. Medially, the superficial layer is the CHL and the deep layer is the SGHL together with the joint capsule. Laterally, the uppermost layer consists of the superficial fibers of the CHL extending to the insertional fibres of the supraspinatus and subscapularis tendons. The next layer is formed of the crossing fibres of the supraspinatus and subscapularis. The subscapularis fibres also form the roof of the bicipital groove. The third layer is composed of the deep fibres of the CHL whose main part is inserted at the greater tuberosity and the smaller part at the lesser tuberosity. The deepest layer is formed of the SGHL and the capsule. In addition to the above mentioned findings, Gagey *et al.*, (1993) identified the fibres of the infraspinatus tendon within the RI.

### **2.1.6. Medial glenohumeral ligament (MGHL)**

Most frequently, the MGHL originates from the supraglenoid tubercle and anterosuperior labrum (Cole *et al.*, 1999) or from the scapular neck (Moseley et Overgaard 1962; Kolts *et al.*, 2001). In relation to the SGHL, Ide *et al.*, 2004 showed that 43% of MGHL had an attachment to the SGHL origin and 57% of MGHL had an attachment to the labrum origin. They also noted a rare variant, the cord-like MGHL without anterosuperior labrum, named a “Buford complex”, in 1% of cases. The MGHL extends latero-inferiorly blending with the antero-lateral joint capsule and the subscapularis tendon, and inserts into the lesser tubercle of the humerus. Kolts *et al.*, (2001) found its tight connection with the so-called spiral glenohumeral ligament (spiral GHL).

The MGHL has the greatest variation in the size, shape and presence of all GHJ ligaments. It can be absent in 12 to 37% of cases (DePalma 1949; Ide *et al.*, 2004).

The MGHL is the primary stabilizer for anterior GHJ stability at 45° and it limits external rotation between 45° – 90° of abduction. It is the secondary stabilizer for inferior translation in the adducted shoulder (Cole *et al.*, 1999).

### **2.1.7. Inferior glenohumeral ligament (IGHL)**

The IGHL is the largest and the most important of the glenohumeral ligaments.

Turkel and colleagues (1981) brought attention to the thickened anterior-superior edge of the IGHL in 78% of shoulders and named it the superior band of the IGHL. They divided the IGHL into the anterior and posterior axillary pouches. According to another opinion there are anterior-inferior and posterior-inferior glenohumeral ligaments (Jerosch *et al.*, 1990). In the most frequently cited study of O’Brien *et al.*, (1990) the IGHL is divided into three parts: the

anterior band (AIGHL), the posterior band (PIGHL), and the interposed axillary pouch (axIGHL). Bigliani *et al.*, (1992) and Ticker *et al.*, (1996) have further challenged the presence of the discrete posterior band and found all regions of the IGHL to be thicker near the glenoid than near the humerus.

Anteriorly, the IGHL originates from the scapular neck and labrum in the area located between 2 and 5 o'clock positions, while posteriorly, the same range of attachment is from 7 to 9 o'clock positions (O'Brien *et al.*, 1990; Ide *et al.*, 2004). The IGHL complex inserts into the humerus at the anatomical neck with a collar-like or with a V-shaped attachment (O'Brien *et al.*, 1990). The surgical neck as the insertion site is mentioned as well (Moseley and Overgaard 1962; Turkel *et al.*, 1981).

The axIGHL runs from the inferior 2/3 of the anterior glenoid to the inferior 1/3 of the humeral head (Burkart and Debski 2002). The AIGHL can be absent in 7 to 25% of cases (Depalma *et al.*, 1949; Turkel *et al.*, 1981; Ide *et al.*, 2004; Steinbeck *et al.*, 1998). The PIGHL is the least commonly found part of the IGHL, which could be identified only in 63 % of the specimens examined (Gohlke *et al.*, 1994).

The AIGHL and the PIGHL are suggested to function as a cruciate construction, tightening alternatively in external or internal rotation (Matsen *et al.*, 1999). The IGHL complex is an important stabilizer for anterior and posterior GHJ instability as well as a primary stabilizer for inferior translation in the abducted shoulder position (Cole *et al.*, 1999).

### 2.1.8. Synovial recesses

Depending on both morphologic and topographic variations of the anterior capsular ligaments of the GHJ, the arrangement of the synovial recesses has been classified into 6 different types (Depalma *et al.*, 1949).

Type 1 has one synovial recess above the MGHL (30%); Type 2 has one recess below the MGHL (2%); Type 3 has two recesses — the superior subscapular recess above and the inferior subscapular recess below the MGHL (40%); Type 4 has no MGHL with the large synovial recess above the IGHL (9%); In Type 5, the MGHL exists in the form of two small synovial folds (5%); Type 6 is characterized by a complete absence of any synovial recess (11%). Similar results are reported in more recent studies (Moseley and Overgaard 1962; O'Brien *et al.*, 1990; Steinbeck *et al.*, 1998). Gohlke *et al.* (1994) modified this classification because Type 4 was not found and was replaced by a variant with three recesses between the anterior glenohumeral ligaments (in 5%), which was not originally described.

Historically, the superior subscapularis bursa is called the foramen of Weitbrecht and the inferior subscapularis recess, the foramen of Rouviere (Yeh *et al.*, 1998). The largest superior subscapularis bursa is present in up to 90% of cases (Moseley and Overgaard 1962).



### 2.1.9. Fasciculus obliquus

In 1910, DeLorme first described the “fasciculus obliquus” — a bundle of fibres passing between the part of the posterior surface of the subscapularis tendon, which joins the MGHL, and the origin of the long head of the triceps tendon (LHT). Strasser (1917) called these fibres “ascending fibres” and further, Landsmeer and Meyers (1959) renamed them the “longitudinal-oblique system” which was identified as part of the subscapularis fascia. Similar findings were reported in more recent anatomical studies (Turkel *et al.*, 1981; Gohlke *et al.*, 1994). A circular fibre bundle on the bursal side of the superior GHJ capsule has been also mentioned the fasciculus obliquus (Jobe 1999; Werner *et al.*, 2000). In the last most detailed anatomical investigation (Kolts *et al.*, 2001) the fasciculus obliquus was recognized as a distinct anterior capsular ligament and was named, according to its appearance, the Lig. glenohumerale spirale (spiral GHL).

Although the biomechanical role of the fasciculus obliquus or the so-called spiral GHL is still uninvestigated, already DeLorme (1910), based on cadaver observations, pointed out that shoulder motion in flexion and in external rotation is obviously controlled by this structure.

### 2.1.10. Posterior capsule

The posterior capsule is the thinnest region of the joint capsule without ligamentous reinforcements (O’Brien *et al.*, 1990). Its role is to limit posterior translation when the shoulder is forward-flexed, adducted and internally rotated (Warren *et al.*, 1984).

## 3. Arthroscopic anatomy of the GHJ

Contemporary arthroscopic equipment and advanced surgical techniques have significantly helped appreciate *in situ* the intra-articular arrangement of the glenohumeral ligaments and normal variants and to differentiate them from pathoanatomic lesions (Levine and Flatow 2000). The anterior glenohumeral ligaments named the SGHL, the MGHL and the IGH by Schlemm in 1853 are best visible arthroscopically from the posterior portal, especially in the tensioned position. The ligaments and the biceps tendon within the RI region can be seen from the anterior arthroscopic portal (Bennet 2001). Some overlapping portions and blending areas within the anterior capsule, as well as the CHL at its origin, in the extracapsular layer, are not arthroscopically visible.

### **3.1. Coracohumeral (CHL) and coracoglenoidal (CGL) ligaments**

The anterior portion of the CHL, arising from the coracoid base, has been visualized from the subacromial space during bursoscopy *via* the lateral portal. The lateral part of the CHL can still be visualized with standard arthroscopy of the GHJ (Bennet 2001). The CGL is the extraarticular structure and is not visible from inside the GHJ.

### **3.2. Rotator cable (RC)**

Arthroscopy of the GHJ shows a consistently identifiable RC that is perpendicular to the supraspinatus tendon, and arches anteriorly and posteriorly to the attachment regions on the humerus (Burkhart *et al.*, 1993).

### **3.3. Superior glenohumeral ligament (SGHL)**

Although the SGHL is almost always present in cadaveric dissection, it is identified only occasionally during shoulder arthroscopy because it may be hidden behind the biceps tendon or be buried deep within the synovium. When it is visualized, it can be identified superior to the subscapularis tendon or near the insertion of the biceps tendon (Andrews *et al.*, 1997). It appears arthroscopically that the SGHL sends a bundle of fibres toward the coracoid process (Detrisac and Johnson 1986). Also, a rare variation of the SGHL, which overrides the biceps tendon origin and attaches to the posterosuperior labrum, has been reported during the shoulder arthroscopic procedure (Pradhan *et al.*, 2001). The most important function of the SGHL is the stabilization of the LHB in its intraarticular course (Werner *et al.*, 2000).

### **3.4. Rotator interval (RI)**

When viewing arthroscopically, the SGHL and the CHL blend within the RI laterally, forming a stabilizing sling or a reflection pulley that encloses the LHB at the entrance into the bicipital groove. Also, deep insertional fibres of the subscapularis tendon at this entrance, which form the floor of this pulley system, can be visualized (Bennett 2001; Habermayer *et al.*, 2004).

### **3.5. Medial glenohumeral ligament (MGHL)**

The arthroscopic appearance of the MGHL is consistent with its intraarticular anatomy described in gross dissectional studies. In an extensive arthroscopic

study, Williams *et al.*, (1994) first described a rare presence of the Buford complex in 1.5% of shoulders, and noted an anterosuperior labral detachment, a sublabral foramen as a normal anatomical variant, in 12% of cases.

### **3.6. Inferior glenohumeral ligament (IGHL)**

Arthroscopically, the AIGHL and the PIGHL are best visualized when the shoulder is in internal or external rotation in varying degrees of abduction (O'Brien *et al.*, 1999). The attachment to the glenoid and labrum and the site of insertion to the humerus of the IGHL complex is clearly evaluable during shoulder arthroscopy (Jobe *et al.*, 1999).

## **4. Histology of the GHJ capsule and ligaments**

Current textbooks of histology define the joint capsule as a dense connective tissue with irregular collagen fibres arrangement, its ligaments consisting of parallel collagen fibres (Bucher and Warteberg 1989; Lüllmann-Rauch 2003).

Several studies have shown the microscopic appearance of the normal GHJ capsule and ligaments (Steiner and Hermann 1989; Clark *et al.*, 1990; O'Brien *et al.*, 1990; Edelson *et al.*, 1991; Cooper *et al.*, 1993; Gohlke *et al.*, 1994; McFarland *et al.*, 2002). Summarizing their results, the GHJ capsule has a synovial layer lining the articular side of the capsule consisting of two or three cell layers of synoviocytes. The next two or three layers of collagen fibres can be loosely packed or dense with a typical wavy pattern having a few fibroblasts, vascular channels and an adipose tissue within its radial and circular arrangement. The macroscopically recognizable ligaments are composed of several layers of collagen fibres of different thickness and orientation, building a complex of cross-linking areas.

## **5. Magnetic resonance imaging of the shoulder**

Magnetic resonance imaging (MRI) has rapidly evolved into an accepted modality for medical imaging of disease processes in soft tissues. The shoulder is the second most commonly imaged joint after the knee in musculoskeletal MRI practice. Shoulder MRI can evaluate a much broader spectrum of pathology than other diagnostic modalities because of superior soft tissue contrast, high spatial resolution, and multiplanar capability (Steinbach *et al.*, 1999). In selected cases, contrast enhancing methods such as direct or indirect magnetic resonance (MR) arthrography are even more precise to distinguish normal anatomy from pathology (Blum *et al.*, 2000; Massengill *et al.*, 1994; Vahlensieck

2000; Stoller 1997; Herzog 1997). In a review of literature it has been shown that shoulder MRI alters primary diagnosis in 23–68%, and management plans in 15–61% of clinical cases (Bearcroft *et al.*, 2000).

A routine imaging protocol includes three orthogonal planes — axial, oblique coronal and oblique sagittal planes — which are performed, depending on suspected pathology and preference of the radiologist, with different image sequences and parameters (Rafii 2004).

On MR imaging the normal capsule appears as a low-signal line, which is best visible near its insertion to the labrum and scapular periosteum (Rafii 2004). At the axial mid-glenoid level, Zlatkin and colleagues (1989) described three types of the anterior capsular insertions. In Type 1, it inserted near the labrum and in Types 2 or 3, a more medial insertion along the scapular neck was noted.

The variable anatomy of the GHJ ligaments from a mere thickening of the capsule to a well-defined cord-like structure, also influences visualization of these ligaments by MRI. Clinical reports and cadaver imaging studies have significantly improved the understanding of the MRI anatomy of the GHJ ligaments and proved that they can be consistently visualized as low-signal intensity or hypointensive bands in all imaging planes (Palmer *et al.*, 1994; Totterman *et al.*, 1994; Liou *et al.*, 1993; Park *et al.*, 2000; Chandnani *et al.*, 1995; Beltran *et al.*, 1997; Chung *et al.*, 2000).

## **6. Clinical relevance of the GHJ capsule and ligaments**

A thorough knowledge of the normal anatomy and variable appearance of the GHJ capsule and ligaments is essential to distinguish between normal and pathologic conditions. This is equally important when evaluating anatomic structures on the diagnostic MR images or intraoperatively during open or arthroscopic shoulder surgery.

Summarizing all available biomechanical data and based on clinical experience, Pagnani and Warren (1994) introduced the “circle concept” of GHJ stability. The circle concept implies that excessive translation in one direction may require damage to restraints on both the same and opposite sides of the joint. There is a functional interplay between the anterior and posterior, and between the superior and inferior components of the capsuloligamentous system. Clinically, this becomes important in shoulder instability where the surgical restoration of a normal anatomy or a nearly normal arrangement of capsule and ligaments of the GHJ is the main goal of treatment (Levine et Flatow 2000; Cole and Warner 1999).

Conversely, scarring and contracture of the GHJ capsule and ligaments have been associated with adhesive capsulitis, prolonged immobilization or chronic retracted rotator cuff tears. In these clinical conditions, partial or complete

capsular release with close shoulder manipulation or surgery is frequently needed (Neer *et al.*, 1992; Cuomo 1999).

Summarizing previous and current anatomical literature, differences in the descriptions and missing details of the GHJ capsule and ligaments as well as schematic drawings in contemporary anatomical textbooks or atlases led us to the investigation of the most intricate superior and anterior parts of the GHJ capsule.

# AIMS OF THE INVESTIGATION

## General aim

To enhance the knowledge of the extra- and intraarticular surgical anatomy and to improve the basis for clinical interpretation of MR images of the shoulder joint capsule and ligaments.

## Specific aims

1. To study the micro- and macroanatomical properties of the superior shoulder joint capsule and, particularly, the region clinically known as the rotator interval, on the embalmed cadaveric shoulder specimens.
2. To study the anatomical composition of the anterior shoulder joint capsule and ligaments focusing on the description of the *fasciculus obliquus* or the so-called spiral GHL on fresh frozen cadaveric shoulder joints.
3. To investigate the MRI anatomy of the so-called spiral GHL and anterior capsular ligaments on fresh frozen cadaveric specimens.
4. To evaluate the intraoperative arthroscopic visibility of the so-called spiral GHL during shoulder arthroscopic surgery on patients.

## MATERIALS AND METHODS

This anatomical and clinical study is based on the shoulder joints of 66 cadaveric specimens and 19 patients. The cadaveric and patient material in four publications are presented in Table 1.

**Table 1**

Study type	Study site	No of shoulder joints male/female	Goals of the study	Publication
anatomical in cadavers	IA LU; IA TU	34	anatomy of CHL and CGL	I Ann Anat 2000
anatomical in cadavers	IA LU; IA TU	19	anatomy of RI	II Ann Anat 2002
anatomical in cadavers	IA IDR, LU	6 (4/2)	macro- and MRI anatomy of spiral GHL	III Eur Radiol 2004
anatomical cadaver and clinical case series	IA LU; DHH	7 specimens 19 patients (4/3; 12/7)	Extra- and intra-articular anatomy of spiral GHL	IV Manuscript (submitted to Arthroscopy 2005)

IA IDR, LU – Institute of Anatomy and Institute of Diagnostic Radiology, Lübeck University

IA LU; DHH – Institute of Anatomy, Lübeck University; Diacor Hospital, Helsinki

IA LU; IA TU – Institute of Anatomy, Lübeck University; Institute of Anatomy, Tartu University

### 1. Study of the rotator interval and superior shoulder joint capsule

#### 1.1. Gross anatomical dissection

Altogether 53 alcohol-formalin-glycerol fixed right shoulder joints (age range 45–78 years; 29 female and 24 male) were investigated. In 19 specimens, the complex anatomical region of the RI was specifically investigated. In 34 cadaver shoulder joints, dissection was focused on precise structural properties of the CHL and CGL.

The soft tissues, clavicle, and shoulder girdle muscles, except the *M. pectoralis minor*, were removed from the shoulder specimens. The extra-articular part of the long head of the biceps tendon within the intertubercular groove was preserved. The acromion was separated from the scapular spine and turned anteriorly together with the acromioclavicular ligament. The muscles and tendons of the rotator cuff were cleaned from the rest of the subacromial bursa and separated from the joint capsule. The ligaments of the superior joint capsule were identified by fine dissection according to the direction of the collagen fibres.

For RI study, the coracoid was cut at its base and moved together with the CHL and CGL posteriorly. The structures within the RI were visualized and the analysis of their relationships was made with the humerus in a neutral position.

## **1.2. Histological investigation**

Light microscopical investigations were carried out on formalin (4%) fixed material taken from different parts of the ligaments and the joint capsule. The tissue samples were embedded in paraplast. Sections of 7  $\mu\text{m}$  thickness were stained with hematoxylin-eosin and after Masson–Goldner with resorcin-fuchsin.

## **2. Study of the anterior shoulder joint capsule**

### **2.1. Gross anatomical dissection**

Thirteen fresh-frozen human forequarter amputation specimens were stored at  $-20^{\circ}\text{C}$  and then slowly thawed at room temperature for 12 to 18 hours before gross anatomic dissection. There were six right and seven left sides; four male and three female cadaver specimens with age range from 63 to 91 years.

Gross dissection was done similarly as described in section 1.1. After separation of the rotator cuff tendons from the joint capsule, ligaments of the anterior joint capsule were identified by fine dissection according to the direction of the bundles of the collagen fibres. The subscapularis bursa was opened to visualize the glenoid labrum and its relationship to the capsular ligaments. To avoid confusing recognition of capsular folds as ligaments, the anatomically identified structures were examined through the total range of shoulder joint motions.



## **2.2. Histological investigation**

Approximately 1.5 cm × 1 cm pieces of the spiral GHL from all shoulder specimens were taken from three different capsular regions: origin, crossing with the MGHL and insertion on to the lesser tubercle of the humerus. The material was fixed in 10 % neutral buffered formalin and embedded in paraffin. Sections with a thickness of 10 µm were stained with hematoxylin and eosin, and were examined by light microscopy.

## **2.3. Magnetic resonance imaging of shoulder specimens**

Six fresh shoulder specimens were examined by MRI on a 1.5 Tesla device (Somatom Symphony (R), Siemens, Erlangen, Germany). The shoulder coil was used in all cases. Three shoulders were investigated without a contrast medium. MR arthrography was performed on all six shoulder specimens. The MR arthrography was done under the fluoroscopic control with injection of 15–20 ml of a contrast solution (1 ml of Omniscan® in 100 ml of saline). We used standard axial, oblique sagittal, and oblique coronal fat saturated views PDW WI (TR 3000 ms, TE 36 ms, SL 3 mm, Matrix (M) 224 x 512, No. of acquisitions (NA) 2, TA (min) axial 3.18, oblique sagittal/coronal 3.54), axial and oblique sagittal T1 W1 (TR 632 ms, TE 14 ms, SL 3 mm, M 256 x 512, NA 3, TA (min) axial 4.32, oblique sagittal 3.46) and DESS 3D W1 (TR 21.5 ms, TE 6.5 ms, SL 1.5 mm, M 217 x 256, NA 1, TA (min) 5.14).

## **2.4. Comparison of magnetic resonance images with gross anatomical specimens**

On MR images we specifically evaluated the MGHL, the spiral GHL, and the anterior band as well as the axillary part of the IGHL complex. Because of the separate position of the SGHL and posterior band of the IGHL complex from that of the spiral GHL, these structures were not evaluated in MR images and during gross anatomic dissection of the shoulder joints.

Since the spiral GHL has not been previously described in the radiological literature, two experienced specialists in musculoskeletal radiology (T.L. and H-B.G.) read the first two MR images after they saw the cadaver specimens and learned the pertinent anatomy. Having become familiar with the expected location of the spiral GHL, the remaining four shoulder MR images were interpreted prior to anatomic dissection. Different evaluations were resolved by consensus.

## 2.5. Arthroscopic evaluation

For the arthroscopic visualization of the spiral GHL, intraoperative videoclips of 19 patients (6 left and 13 right shoulders; 12 male and 7 female; age range 33–64 years) were retrospectively analysed by two independent, experienced shoulder surgeons (H. H. and M. M.). Different opinions were resolved by consensus.

All patients had a pre- and intraoperative diagnosis of impingement syndrome or rotator cuff disease with normal labrum, anterior capsular ligaments and subscapularis tendon.

Standard shoulder arthroscopy was performed with patients under general endotracheal anaesthesia. Patients were positioned in the lateral decubitus position and the arm was held in 70° of abduction and 10° of forward flexion. The glenohumeral joints were distended with Ringer's lactate solution. With 30° degrees oblique arthroscope inserted through a standard posterior arthroscopy portal, the anterior capsule, ligaments and subscapularis tendon were examined in different shoulder joint positions.

On arthroscopic videos, we specifically focused on the spiral GHL and its relationship with the subscapularis tendon, the MGHL, the AIGHL and the AxIGHL.

# RESULTS AND DISCUSSION

## 1. Study of the rotator interval and superior shoulder joint capsule

### 1.1. Gross anatomical dissection (Figures 1–3; 5–8)

The CHL and CGL were identified in all investigated shoulder specimens.

The CHL was found to have two distinct parts. The fibres of the superior part began at the medioposterior surface of the coracoid process. The stronger inferior part originated from lateroposterior surface of the coracoid process and CGL which always formed the medial margin for CHL. The anterior portion of the inferior part of the CHL had no consistent macroscopic structure, the posterior portion had a tendinous appearance with clearly visible parallelly oriented bundles of collagen fibres.

Both parts of the CHL coursed latero-posteriorly under the tendon of the supraspinatus muscle and inserted into a macroscopically visible semicircular band.

The CGL began in the middle of the upper posterior surface of the coracoid process between the limbs of the coracoacromial ligament and inserted into the supraglenoid tubercle and posterior to it on the scapular neck. In 38 of 53 specimens (72%) the CGL was partially formed by continuing fibres of the tendon of pectoralis minor muscle.

The semicircular band was noted in all specimens. It spread between the superior facets of the minor and major tubercles and the course of its fibres was transverse to the longitudinal axis of the supra- and infraspinatus tendons. Fibres of the semicircular band ran superficially from the lateral corner of the RI to the insertion area between the tendons of the infraspinatus and teres minor muscles.

The RI was identified as a complex anatomical structure including CHL, CGL, semicircular band, SGHL, MGH and anterior fibres of the supraspinatus tendon in all the 19 investigated shoulder joints. There were no differences between male and female specimens.

Approximately 1 cm wide semicircular capsular band was anteriorly attached to the superior facets of the major and lesser tubercles. The fibres of this band bridged the bicipital groove above the THL and it coursed posteriorly within the joint capsule as mentioned above. The anterior fibres of the supraspinatus tendon fused with the semicircular band and formed the lateral corner for the RI. An additional insertion of the anterior fibres of the supraspinatus tendon on the lesser tubercle was noted in 9 of 19 specimens (47%).

The CGL formed the medial border for the RI. The inferior part of the CHL fused tightly with SGHL within the midline of the RI and formed its anterior

border close to the tendon of the subscapularis muscle. The superior part of the CHL made up the posterior margin for the RI.

After cutting the coracoid process at its base and moving it with CHL and CGL backwards, the next layer of the superior capsule was exposed.

Parallely oriented collagen fibres, which arose from the supraglenoid region, coursed in medio-lateral and cranio-caudal directions. The medio-laterally oriented fibres made up the SGHL and cranio-caudal fibres formed the MGHL. The direct fibres of the SGHL bordered the tendon of the biceps brachii anteriorly and inserted on the lesser tubercle. The oblique fibres of the SGHL fused with overlaying CHL, coursed over the intraarticular part of the biceps brachii tendon and inserted on the semicircular band.

The most medial part of the deep layer of the RI was composed of the cranio-caudally oriented fibres of the MGHL. This ligament arose from the supraglenoid region and coursed under the subscapularis muscle into the anterior joint capsule.

## **1.2. Histological findings (Figure 4)**

On light microscopy, the superior part of the CHL consisted of irregularly arranged bundles of collagen fibres, interspersed with strands of loose connective tissue, fat and blood vessels. The structure of the inferior part of the CHL was anteriorly the same. Posteriorly, dense connective tissue was dominating in the extracellular matrix. The CGL was composed of regular dense connective tissue with parallely oriented bundles of collagen fibres. Good vascularisation of investigated ligaments was noted.

## **1.3. Discussion**

The results of our dissection of the CHL, CGL and RI areas of the shoulder joint capsule differ from the classical description of analogous results in the literature.

The most frequent opinion in current textbooks anatomy (Agur 1991; Moore 1992; Tillmann and Töndury 1987) is that the CHL arises from the base and the posterior surface of the coracoid process. In the orthopaedic literature, lateral surface of the coracoid is mainly mentioned as the place of origin of the CHL (Cole and Warner 1999; Cooper *et al.*, 1993; Burkhead *et al.*, 1999). In addition to the well known origin from coracoid process, we found that the CHL arose partially from a distinct, macroscopically recognizable ligamentous structure — the CGL, which was present in all the shoulder specimens. Although this strong fibrous band has already been described by Macalister (1867) and Sappey (1867) its clinical importance still remains unclear. In the only contemporary work by Weinstabl *et al.* (1986) close relationship was demonstrated between

the CGL and the tendon of the pectoralis minor muscle. Variable anatomy of the CGL in our study supports the previous opinion that the CGL might be a remnant of the pectoralis minor muscle (Macalister 1867; Weinstabl *et al.*, 1986; Agur 1991).

Although the CHL varied individually in shape and size, two separate parts with different sites of origin were present in all our investigated specimens.

The superior thinner part of the CHL was present in only 6% of cases in the study of Weinstabl (1986). The existence of similar fibres running from the CHL to the coracoacromial ligament (CAL) is noted also by Jerosch *et al.*, (1990). As investigation was not concentrated on the anatomical details of the CHL in these studies and because of the close position of the superior part of the CHL to the CAL, it might be simply removed together with CAL during dissection.

Another interesting finding that we obtained, was the insertion of the CHL not directly to the major and lesser tubercles, as generally described in textbooks of anatomy and in current literature (Cole and Warner 1999), but to the macroscopically recognizable transverse semicircular band.

The existence of the similar transverse capsular fibres and their connections with the CHL was first described by Clark *et al.*, (1990). They always noted it on the synovial surface of the capsule when the joint was opened during anatomical dissection. Clark et Harrymann (1992) proposed that the transverse band between the capsule and the supraspinatus tendon might be a posteriorly extending branch of the CHL.

However, our fine extraarticular dissection showed that it is a distinct anatomical structure. This is supported with previous studies by Gohlke *et al.* (1994) and Werner *et al.* (2000) who observed strong circular fibres of the transverse band under a polarized microscope. The same concerns the intraarticular description of this structure as a “rotator cable” by Burkhart *et al.* (1993).

The rotator cable (Burkhart *et al.*, 1993) was consistently found inside the shoulder joint specimens and it extended anteriorly to the biceps and posteriorly to the inferior border of the infraspinatus tendons, spanning the insertions of the infra- and supraspinatus tendon. Based on their clinical experience and findings of anatomical dissection, the concept of rotator cable and the biomechanical model for the rotator cuff tears was developed.

The results of the recent biomechanical shoulder tests (Hadler *et al.*, 2002) support this concept and correspond to the clinical observation that patients with small rupture of the rotator cuff may present without a loss of shoulder strength. Muscle retraction after rotator cable detachment from its insertion points is an important factor responsible for loss of shoulder function following large rotator cuff ruptures.

We focused on the extraarticular macroscopic anatomy of this structure which was similar to its intraarticular appearance (Burkhart *et al.*, 1993). Our results of gross dissection also support previous microscopic findings (Werner *et al.*, 2000) which have described the transverse band as an important part of the stabilizing fibrous sling for LHB in the RI. In addition, extraarticular investi-

gation allowed us to demonstrate more detailed relation of the rotator cable to the SGHL, CHL, LHB and RI. Because of its shape and position between the major and lesser tubercles we propose to name it the semicircular ligament (SCL).

The present results confirm the currently accepted opinion that the RI is a distinct anatomical complex of tendinous and ligamentous structures that has a distinct pathology (Fitzpatrick *et al.*, 2003). According to the anatomical position of structures in this study, the RI can be divided into lateral, medio-superior and medio-inferior parts. These three parts are composed of different ligaments. The lateral and medial segments occupy approximately equal halves of the RI.

The division of the RI into lateral and medial parts and the medial part into two separate layers correlates with an earlier anatomical study (Jost *et al.*, 2000). In spite of this several differences were found.

Although the CHL is one of the key structures of the RI (Agur 1991; Clark and Harrymann 1992; Jost *et al.*, 2000), our results showed that the so-called SCL and the tendon of the supraspinatus muscle are the main structures of the lateral part of the RI.

Since the extracapsular anatomy of the SCL has not been precisely investigated before, it was recognized only as a posterior prolongation of the CHL (Clark *et al.*, 1990). In addition, the lateral insertion of the CHL has been found difficult to delineate which, rather, represents a folded portion of the anterosuperior capsule (Cooper *et al.*, 1993).

The course of the fibres of the CHL within different layers and the insertion sites in the lateral RI (Jost *et al.*, 2000) is actually similar to our finding where these fibres were demonstrated, instead of CHL as a macroscopically recognizable part of the SCL.

The extension of the anterior portion of the supraspinatus tendon to the lesser tubercle and connection with the tendon of the subscapularis muscle have been previously demonstrated (Kolts *et al.*, 1992; Jost *et al.*, 2000).

The structural elements of the mediosuperior part of the RI were the CHL and CGL.

Despite the previous anatomical studies (Weinstabl *et al.*, 1986; Clark *et al.*, 1990) we describe for first time the CGL as a consistent macroscopical structure of the RI.

The medio-inferior part of the RI is composed of the SGHL and MGHL. Because of its anterosuperior position, the SGHL is classically described as the second main structural component of the RI and also, as an anterior capsular ligament. The present findings support the previous statement that the SGHL helps to make up a stabilizing ligamentous network for the intraarticular part of the LHB (Werner *et al.*, 2000). The insertion of the oblique fibres of the SGHL and the CHL into the SCL explains the reason for the tight connection between two ligaments before the attachment (Ferrari 1990).

The MGHL is an anterior capsular ligament and it is not described in the literature as a component of the RI. In spite of this, the MGHL arises near the

SGHL and according to our gross anatomical dissection, its upper segment could be identified as the most inferior part of the RI.

There has been increasing interest in RI because of intraoperative defects within this capsular area that have been associated with recurrent anteroinferior and multidirectional shoulder instability (Neer and Foster 1980; Harryman *et al.*, 1992). Several open and arthroscopic surgical techniques have been published as a supplement or isolated procedure for closure of RI defects (Field *et al.*, 1995; Treacy *et al.*, 1997; Gartsman *et al.*, 1999). Also, trauma, degenerative changes or anterosuperior impingement may be the possible causes of injuries of the tendoligamentous stabilizing sling for LHB, the pulley system, which represents an important part of the RI. A pulley lesion leads to instability of the LHB, partial tears of the subscapularis tendon and lesions of the LHB itself (Habermayer *et al.*, 2004).

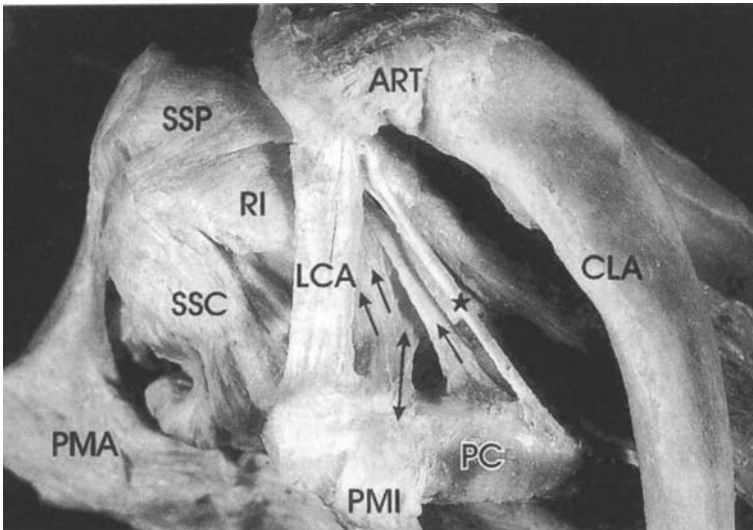
## **2. Study of the anterior shoulder joint capsule**

### **2.1. Gross anatomical dissection (Figures 9–11)**

The spiral GHL was present in all 13 dissected shoulder joint specimens. It arose as a separate band from the region of the infraglenoid tubercle and the long head of the triceps muscle. The ligament coursed cranially in the superficial layer of the anterior shoulder joint capsule, crossing and fusing with the underlying IGHL. After establishing a tight connection with the MGHL, it fused with the postero-cranial surface of the subscapularis tendon. The ligament and the tendon inserted together on the lesser tubercle of the humerus. The spiral appearance of the oblique, ascending capsular ligament was clearly visible with the humerus in abduction and in external rotation.

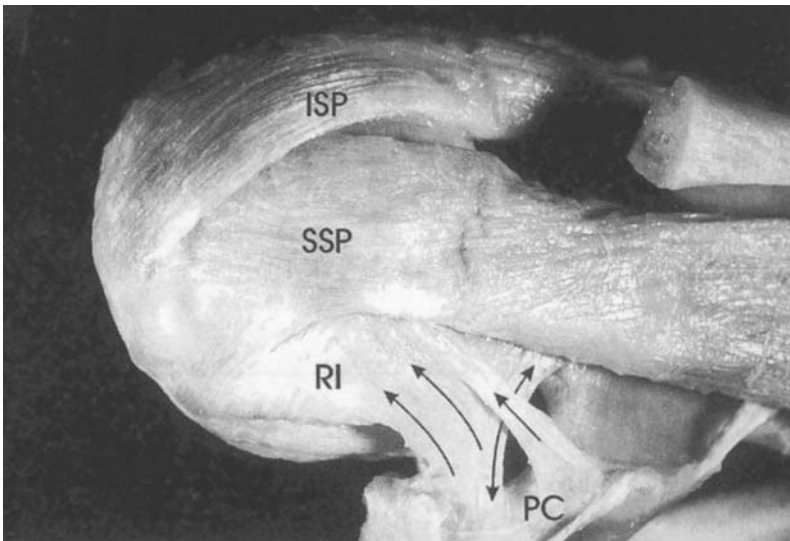
The MGHL originated from the superior neck of the scapula and antero-superior labrum. Its caudal course under the subscapularis tendon crossed with the ascending fibres of the spiral GHL. With the humerus in abduction and in external rotation, the spiral GHL tensioned and turned the MGHL from the vertical to nearly horizontal position. After crossing with the spiral GHL, the MGHL fused with the lateral joint capsule and was not clearly visible within its course to the lesser tubercle of the humerus. The MGHL was absent in three glenohumeral joints. The absence of the MGHL did not influence the anatomical position or course of the spiral GHL fibres.

The IGHL complex was present in all the 13 investigated shoulders. It originated from the antero-inferior neck of the scapula, coursed under the spiral GHL in the latero-caudal direction, and inserted on the anatomical neck of the humerus. The anterior thickening of the IGHL complex was not recognizable on the extra-articular side of the joint capsule.



**Figure 1. Antero-superior view of a right shoulder joint.**

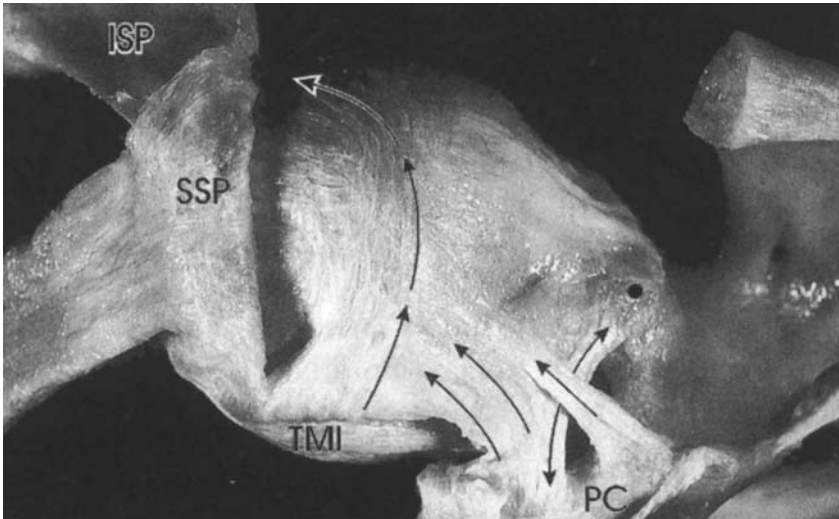
Muscles of the shoulder girdle except the M. pectoralis minor (PMI) have been removed. The CGL (↕) continues the course of fibres of the PMI tendon. The superior part of the CHL (→) begins below the posterior limb (★) of the Lig. coracoacromiale (LCA★); the inferior part of the CHL (↕) originates from the Processus coracoideus (PC) and the CGL, which separates it from the base of the PC. CLA – Clavicula, ART – art. acromioclavicularis; SSP – supraspinatus muscle; SSC – subscapularis muscle; PMA – pectoralis major muscle; RI – rotator interval.



**Figure 2. Superior view of a right shoulder joint.**

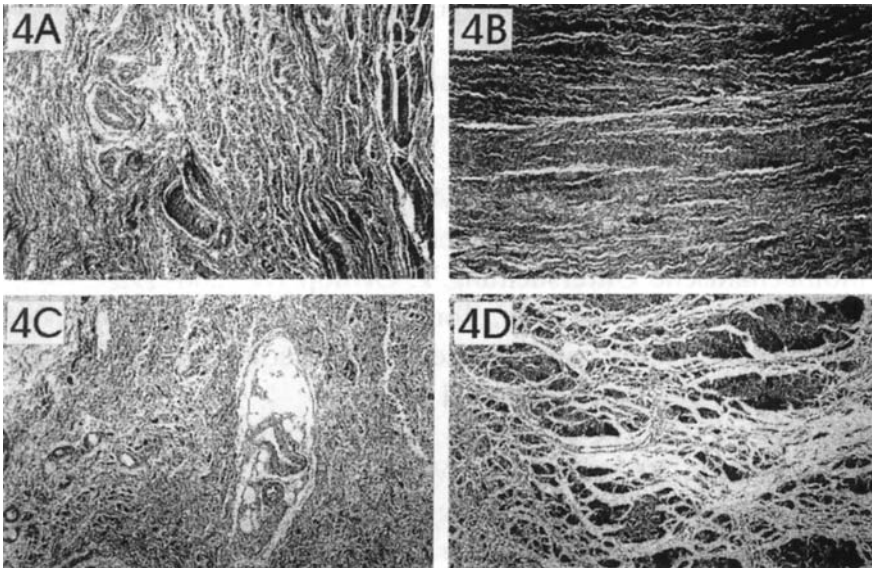
Acromion together with clavicle, acromioclavicular joint and coracoacromial ligament are drawn the side. The superior part of the CHL (→) arises from the medio-posterior margin of the Processus coracoideus (PC); CGL (↕) originates from the superior and posterior surfaces of the PC and runs towards the supraglenoid tubercle. The inferior part of the CHL (↕) is closely connected with the CGL, arising from the tip of PC and is medially limited by the CGL. Both parts of the CHL are running into the rotator interval (RI) under the tendon of the supraspinatus muscle (SSP). ISP – infraspinatus muscle.





**Figure 3. Superior view of a right shoulder joint.**

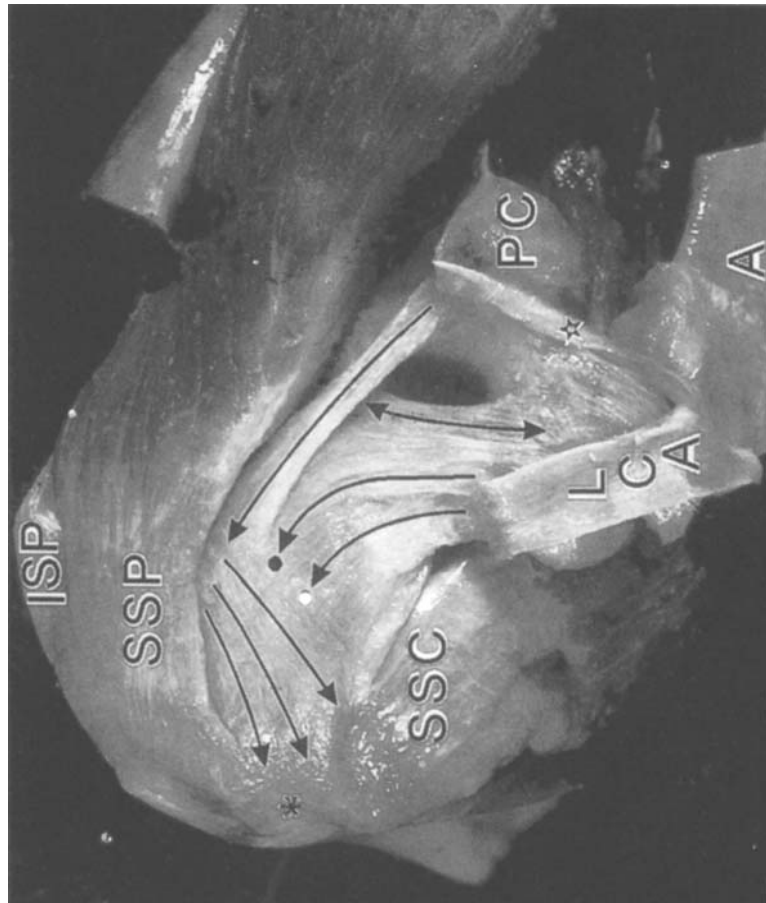
Tendons of the supra- and infraspinatus muscles are separated from the joint capsule. Superior (→) and inferior (↑↑) parts of the CHL run into a macroscopically visible capsular band – semicircular ligament (→→→) and do not directly reach the tubercles of the Humerus. SSP – supraspinatus muscle; (↕) – CGL; TMI – Tuberculum minus; ● – supraglenoid tubercle, PC – Processus coracoideus.



**Figure 4. Light microscopical investigation of the CHL and CGL.**

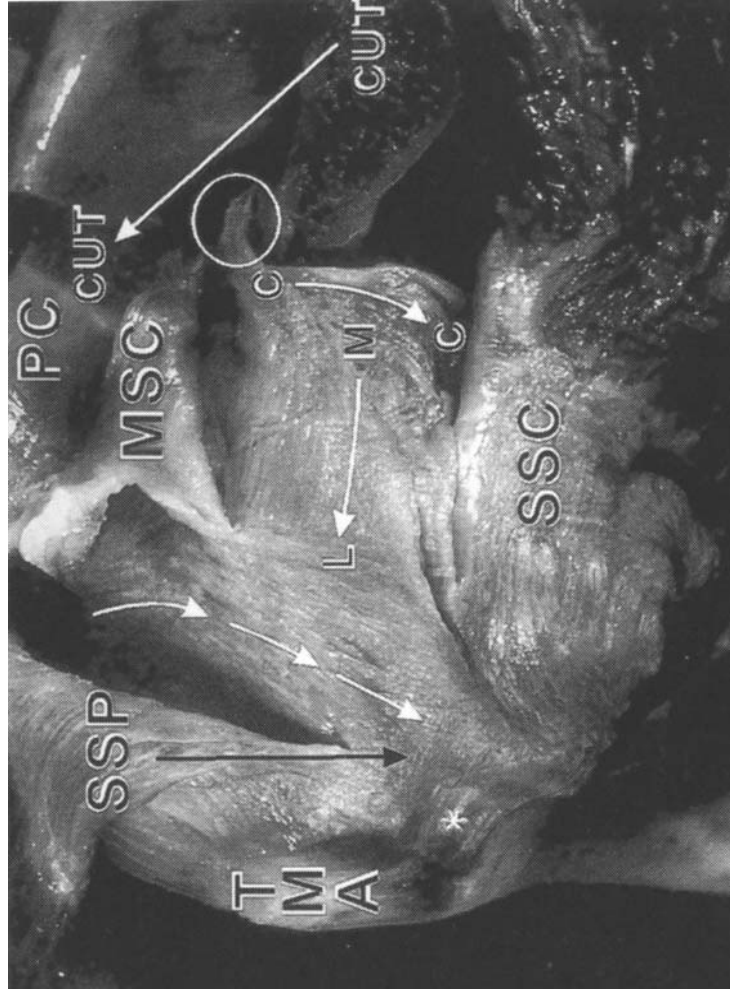
- A. Longitudinal section of the CHL shows irregularly organized bundles of collagen fibres, interspersed with wide strands of loose connective tissue.
- B. Longitudinal section of the CGL demonstrates typical regular dense connective tissue with parallel oriented bundles of collagen fibres.
- C. Transverse section of the inferior part of the CHL, which is anteriorly composed of loose connective tissue with collagen fibres running in all directions.
- D. Transverse section of the inferior part of the CHL. Posteriorly, its histological picture is similar to the tendon, with bundles of collagen fibres surrounded by loose connective tissue.





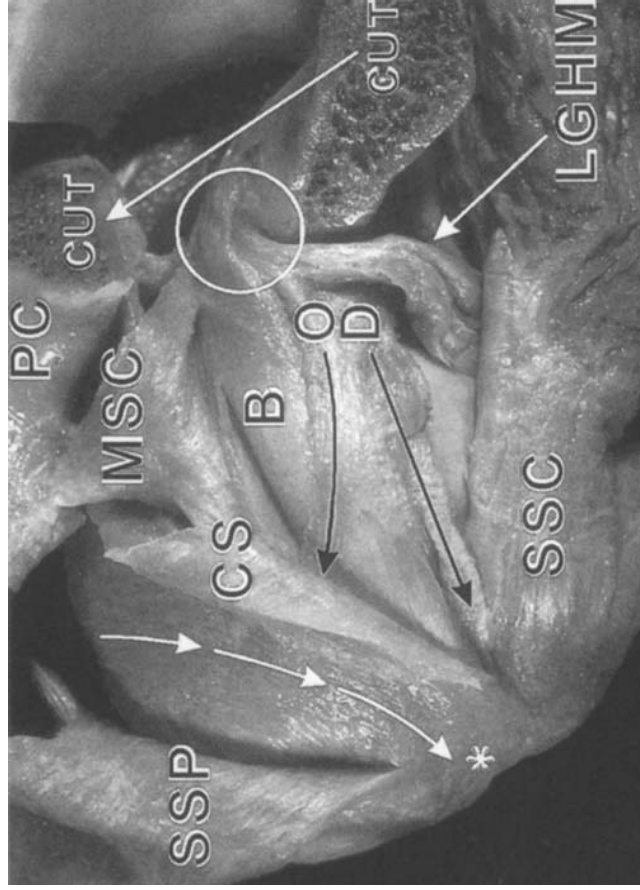
**Figure 6. Medio-superior view of the same right shoulder joint.**

Acromion (A) together with coracoacromial ligament (LCA; ★) is drawn to the anterior side. The superior part of the CHL (↑) runs nearly parallel to the tendon of the supraspinatus muscle into the semicircular ligament (↑↑). The CGL (↓) courses under the supraspinatus muscle (SSP) towards the supraglenoid tubercle. The inferior part of the CHL (→○→●) arises from the tip of the Processus coracoideus (PC) and the CGL. The anterior part of the inferior CHL (→○) is without special macroscopical structure, whereas the posterior part (→●) has a tendinous appearance. The two parts of the CHL insert in the middle of the rotator interval into the semicircular ligament. ISP – infraspinatus muscle; SSC – subscapularis muscle; \* – transverse humeral ligament.



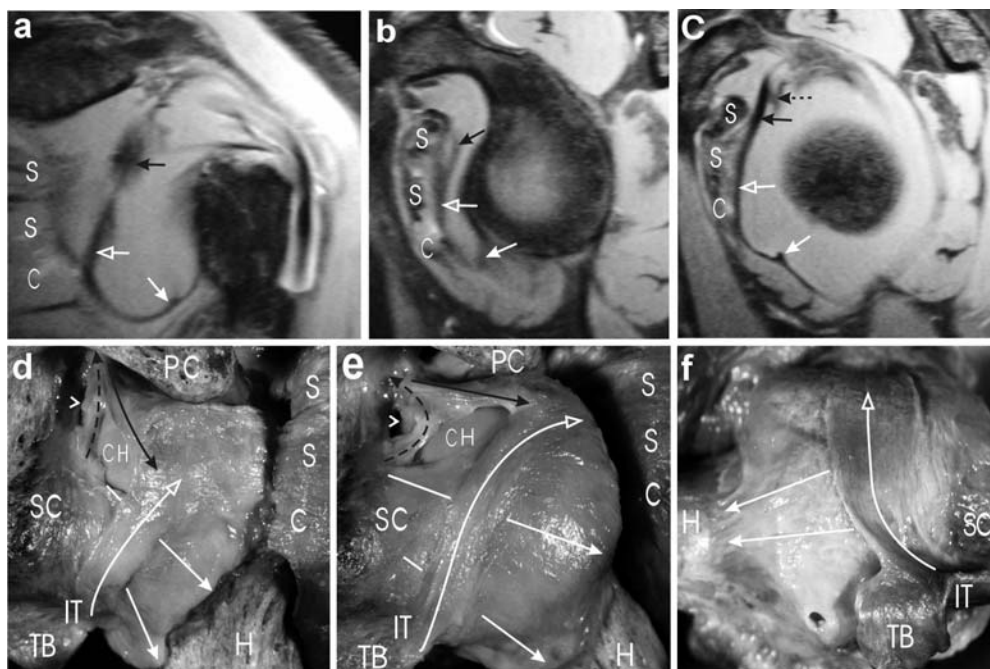
**Figure 7. Antero-superior view of the same right shoulder joint.**

The supraspinatus muscle (SSP) is separated from the superior joint capsule and placed laterally. The Processus coracoideus (PC) has been cut (CUT→ CUT) at its base. The medio-superior capsule (MSC) and CHL is separated from the medio-inferior capsule and removed backwards together with the PC. The rotator interval is laterally composed of the semicircular ligament (→→→→) and the anterior supraspinatus tendon (SSP) fibres. The medio-inferior capsular layer shows medio-lateral (M → L) and cranio-caudal (C → C) fibre arrangement arising from the region of the supraglenoid tubercle (○). The medio-laterally oriented fibres insert at the semicircular ligament, the cranio-caudally arranged bundle courses under the tendon of the subscapularis muscle (SSC) into the joint capsule. TMA – Tuberculum majus; \* – transverse humeral ligament.



**Figure 8. Antero-superior view of the same right shoulder joint.**

Supraspinatus muscle (SSP) is separated from the superior joint capsule and moved laterally. Processus coracoideus (PC) has been cut (CUT → CUT) at its base. The CHL and CGL, which compose the medio-superior joint capsule (MSC), have been separated from the medio-inferior capsule and moved backwards together with the PC. The fibre arrangement of the medio-inferior part of the rotator interval is visualized after removing a thin capsular sheet (CS) of connective tissue to the lateral side. The direct (D →) and oblique (O →) fibres of the superior glenohumeral ligament (SGHL) originate from the region of the supraglenoid tubercle (○). The direct fibres course medio-laterally towards the Tuberculum minus parallel to the intra-articular portion of the long head of the biceps brachii tendon (B). The oblique fibres course over the intra-articular portion of the B and insert into the semicircular ligament (→→→). The middle glenohumeral ligament (LGHM) arises together with the SGHL from the region of the supraglenoid tubercle and courses cranio-caudally under the subscapularis muscle (SSC) into the joint capsule, occupying the most medial position within the medio-inferior part of the rotator interval. \* – transverse humeral ligament.



**Figure 9**

**a-c MR arthrograms of a left shoulder with MGHL. PD-WI fat-saturated (fs); TR/TE=3,000/36 ms.**

**a** Oblique coronal image shows the MGHL (*black arrow*), an anterior capsular folding corresponding to the location of the spiral GHL (*white arrow*) and the axillary part of the IGHL (*dotted white arrow*).

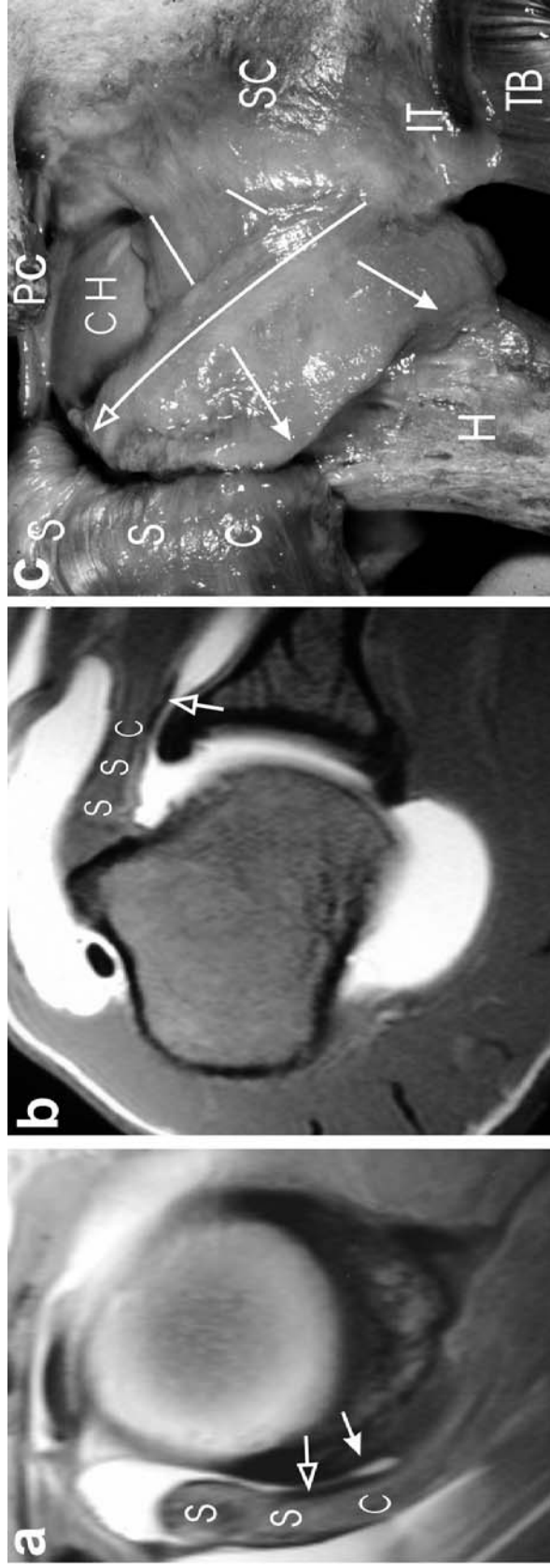
**b, c** Subsequent oblique sagittal images show anterosuperior labrum (*dotted black arrow*), the MGHL (*black arrow*), the anterior capsular section with spiral GHL (*white arrow*) and the anterior band of the IGHL (*dotted white arrow*).

**d-f Photographs of an anatomic dissection of a left shoulder specimen with MGHL.**

**d, e** The MGHL (*black arrow*) and visible capsular thickening — the spiral GHL (*white arrow*) — fuse with the anterior capsule, which has been separated from the subscapularis muscle (SSC). The IGHL (*dotted white arrows*) pass deep to the spiral GHL. A normal variation of the anterosuperior labrum (*dotted black arrow*) with sublateral foramen (*asterisk*) is noted.

**e** In abduction and external rotation, the anterior capsular structures come under tension. The course of the spiral GHL and its fusion with MGHL is clearly demonstrated.

**f** Photograph of an axillary view of a right shoulder specimen in abduction demonstrates the spiral GHL (*white arrow*) origin from the infraglenoid tubercle and its superficial course over the taut IGHL (*dotted white arrows*). PC – Processus coracoideus, CH – Caput humeri, SSC – subscapularis muscle, SC – Scapula, H – Humerus, IT – infraglenoid tubercle, TB – tendon of the triceps brachii muscle.



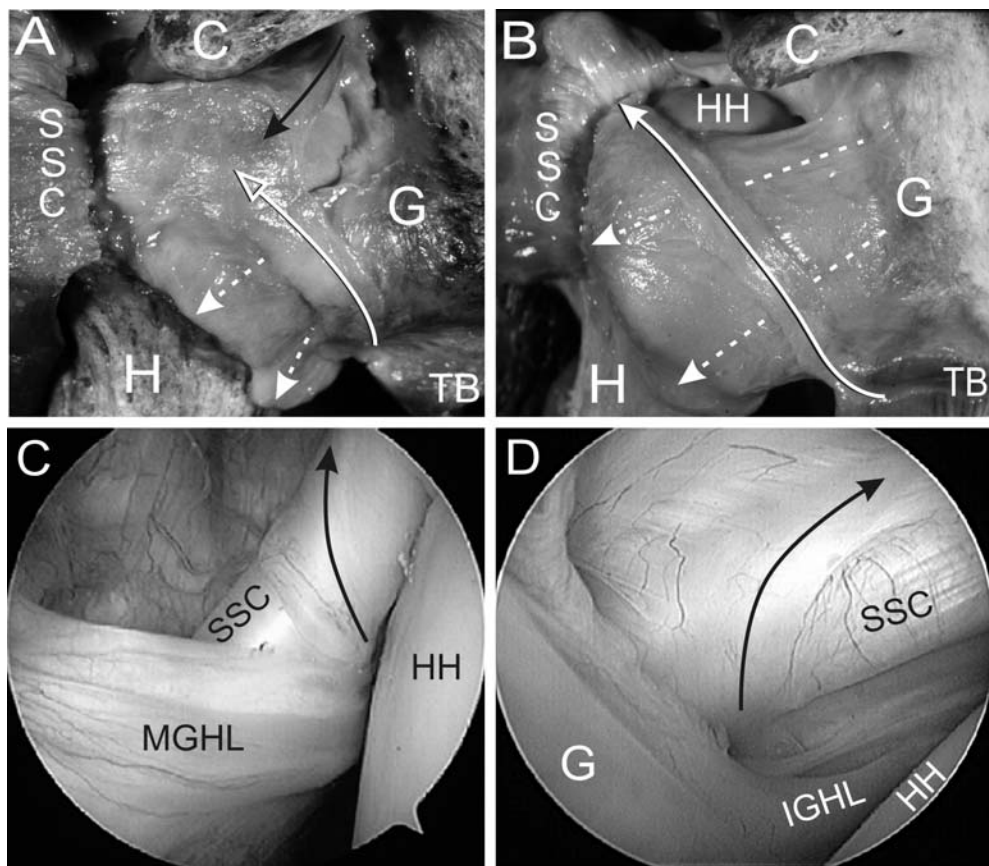
**Figure 10. a–b MR arthrograms of a left shoulder without MGHL.**

**a** Oblique sagittal PD-WI; fs; TR/TE=3,000/36 MR arthrogram of a left shoulder demonstrates the anterior band of the IGHL (*dotted white arrow*) in the deep layer and the spiral GHL (*white arrow*) in the superficial layer of the shoulder joint capsule.

**b** Axial T1-WI; fs; TR/TE=632/14 ms scan — the spiral GHL runs perpendicular to the plane of imaging and is seen as a low signal intensity stripe (*white arrow*) within the anterior capsule. The MGHL is absent on both images.

**c Photograph of a right shoulder specimen without the MGHL.**

The IGHL complex (*dotted white arrows*) is visible together with the spiral GHL (*white arrow*). PC – Processus coracoideus, CH – Caput humeri, SSC – subscapularis muscle, SC – Scapula, H – Humerus, IT – infraglenoid tubercle, TB – tendon of the triceps brachii muscle.



**Figure 11. Photographs of an anatomical dissection and clinical arthroscopic procedures on the right shoulder joint with MGHL (A, C) and without MGHL (B, D).**

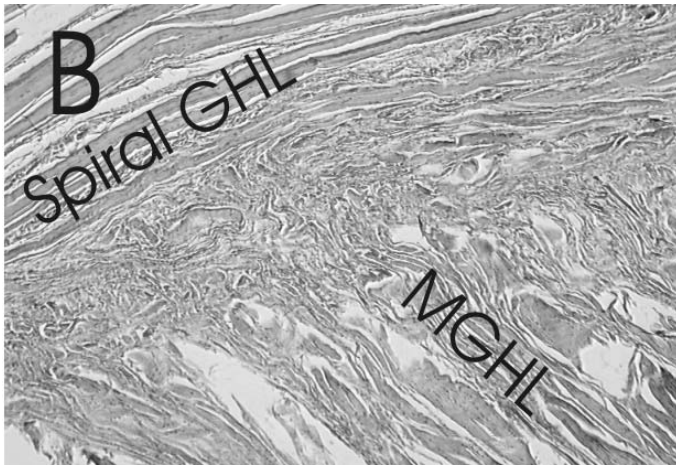
(A) Visible capsular thickening — the spiral GHL (*white arrow*) and MGHL (*black arrow*) fuse within the anterior capsule, which has been separated from the subscapularis tendon (SSC). The IGHL runs deep to the spiral GHL (*white dotted arrows*).

(B) The course of the spiral GHL from the infraglenoid tubercle to the lesser tubercle of the humerus is clearly visible under tension in abduction and in external rotation. The absence of the MGHL does not influence the basic anatomical properties of the spiral GHL.

(C) Intra-articular view through a standard posterior arthroscopy portal shows the spiral GHL (*black arrow*) as an ascending bundle of fibres overlapping the cranio-lateral margin of the subscapularis tendon which is partially veiled by the MGHL.

(D) In absence of the MGHL, the anterior band of the IGHL and a relatively more pronounced part of the spiral GHL are visible. C – coracoid process; HH – humeral head; SSC – subscapularis tendon; G – Glenoid; H – Humerus; TB – tendon of the triceps brachii muscle).





**Figure 12.** Histological appearance of the spiral GHL at the insertion onto the lesser tubercle of the humerus (A), crossing with the MGHL (B) and at the origin (C). In all parts, the spiral GHL displays features of the dense connective tissue with the parallelly oriented bundles of collagen fibres.

In addition, the sublabral foramen was observed located between the antero-superior labrum and the underlying glenoid rim in two specimens.

## **2.2. Histological findings (Figure 12)**

In all shoulder specimens, the three investigated parts (caudal, middle and cranial) of the spiral GHL showed typical features of the dense connective tissue with the parallelly oriented bundles of collagen fibres, which is typical of a ligamentous structure.

## **2.3. Magnetic resonance imaging of shoulder specimens (Figures 9 and 10)**

The ligaments of the anterior shoulder joint capsule were best seen on axial (T1 WI, PDW WI, DESS) and oblique sagittal (T1 WI and PDW WI) oriented images after MR arthrography. In one of six shoulders, the oblique coronal sections were useful for detecting MGHL and spiral GHL.

The spiral GHL was detectable as a low signal intensity stripe on MR images along its course within the anterior joint capsule in all six specimens. The ligament was not found in two of three shoulder MR images without arthrography.

The MGHL was absent on MR images in two shoulder specimens, which was confirmed by subsequent gross dissections.

The IGHL was seen on all MR arthrograms as a continuous low signal intensity band with an origin on the anterior and inferior parts of the scapular neck and an insertion on the neck of humerus. The anterior band of the IGHL complex became clearly recognizable on the oblique sagittal plane images.

## **2.4. Arthroscopic anatomy (Figure 11)**

The spiral GHL was identified in 9 of the 19 evaluated cases (47.4%). The major inferior part of the spiral GHL was concealed by the MGHL, the AIGHL and AxIGHL. After crossing the MGHL, a subtle obliquely ascending capsular thickening of the spiral GHL became visible on the latero-superior surface of the subscapularis tendon. The blending cranio-lateral part of the spiral GHL and subscapularis tendon fibres inserted together to the upper medial margin of the lesser tubercle of the humerus. The MGHL originated from anterosuperior labrum, blended with the overlapping spiral GHL and fused with the lateral joint

capsule. The MGHL was absent in 2 of the 19 shoulders (10.5%). In these cases, relatively more pronounced bundle appearance of the spiral GHL was noted. The AIGHL originated from the area between the 2 and 4 o'clock positions on the right side and between the 10 and 8 o'clock positions on the left shoulders. It inserted on the humerus below the articular margin of the humeral head and was found in 18 of the 19 cases (94.7%).

## 2.5. Discussion

The results of this study confirm the existence of an additional glenohumeral ligament within the superficial layer of the anterior shoulder joint capsule. We recognized its oblique course through the midline of the anterior joint capsule in all the investigated shoulder specimens and on MR images with arthrography. On patients, we identified it only in 47.4% of all the cases during arthroscopic shoulder surgery.

There might be several explanations for the late description of the so-called spiral GHL. The earlier extraarticular descriptions of the GHJ capsule did not focus mainly on the macroscopic properties of the "fasciculus obliquus" (DeLorme 1910), but the whole GHJ capsule and its ligaments were investigated emphasizing their relationship in different GHJ positions. The entire shoulder region was studied by Landsmeer and Meyers in 1959, where the same structure was exposed as a part of the subscapularis fascia. The subscapularis tendon was not completely separated and the anterior capsule was not finely dissected in the most recent extracapsular GHJ investigation (Ferrari 1990) with no description of this structure. Partial destruction or incomplete dissection of the spiral GHL might be the reason for this in these studies. Also, most anatomical investigations have used intraarticular approach, in which case the other anterior capsular ligaments are best seen concealing at the same time the main part of the spiral GHL together with the subscapularis tendon (DePalma *et al.*, 1949; Yeh *et al.*, 1998; Steinbeck *et al.*, 1998; O'Brien *et al.*, 1990; Ide *et al.*, 2004; Wright *et al.*, 2001)

Our findings on fresh shoulder joint specimens and on patients support the results of previous study (Kolts *et al.*, 2001) where the spiral GHL was described as a separate capsular ligament, which could not be visible from inside of the GHJ. In addition, its ligamentous structure of parallelly oriented bundles of collagen fibres was demonstrated. Our histological results support the findings of other study (Gohlke 1994) and add the morphologic description through the whole course of the spiral GHL.

Although, the arthroscopy has significantly improved current understanding of the GHJ anatomy (Levine and Flatow 2000), we found no descriptions in literature corresponding to the intra-articular fibres of the spiral GHL. This can be explained by the fact that only approximately 25% of the entire subscapularis tendon can be arthroscopically seen (Wright *et al.*, 2001), being at the same time

the largest rotator cuff tendon of the shoulder. Even if noted before on arthroscopic shoulder surgery, we realize that this fine intra-articular bundle of fibres upon the subscapularis tendon could be difficult to identify due to the limited view of this distinct structure, which is clearly seen from the extra-articular side of the capsule.

There are yet no biomechanical studies about the function of the spiral GHL. However, recent measurements of the nonrecoverable strain in the anterior glenohumeral joint capsule resulting from joint subluxation, showed that maximum strain vectors were oriented diagonally across the AIGHL from the inferior edge of the glenoid to the superior humeral insertion (Malicky *et al.*, 2002). The authors propose that this orientation may be relevant to the selection of a capsular shift procedure to remove the capsular redundancy without restricting the range of motion. Despite no biomechanical tests, our study brings attention to the fact that the spiral GHL follows the direction of these demonstrated maximum strain vectors. In addition, we showed that during motion, the spiral GHL influences the position of the MGHL, which is an important stabilizer of the GHJ. It raises the suggestion that the role of the spiral GHL in the GHJ function and different pathologic conditions might be currently underestimated.

MR imaging has become the method of choice in differentiation between the normal anatomy and pathologies of the shoulder joint (Steinbach *et al.*, 1999). We showed the macroscopic appearance of the spiral GHL and its close position to the MGHL and IIGHL on MR images, which can be used during the clinical interpretation of the MR scans. Judicious use of MRI can have a significant impact on clinical decisions (Sher *et al.*, 1998). Our results support the current opinion that direct MR arthrography expands the capacities of conventional MR imaging (Elentuck and Palmer 2004; Stoller 1997). According to the literature (Steinbach *et al.*, 1999) and our experience, GHL-s are visible as low signal intensity stripes whose appearance depends on MRI plane and course of a particular ligament.

In the orthopaedic literature, tears of the subscapularis tendon due to trauma or chronic overuse injuries are being increasingly emphasized as a cause of shoulder pain (Gerber *et al.*, 1996; Burkhart and Tehrani 2002; Lo and Burkhart 2003). The same concerns the well-known connection between anterior capsular injury and recurrent shoulder instability (Levine and Flatow 2000). The results of this study indicate that the spiral GHL might be involved in these pathologies.

Gross, arthroscopic and MRI anatomy of the MGHL in our study confirms previous results (Kolts *et al.*, 2001; Steinbeck *et al.*, 1998; Wright *et al.*, 2001). Its remarkable variability and possible absence have been recognized. Clinically, lesion or complete absence of the MGHL has been associated with recurrent anterior shoulder instability (Townley 1950; Morgan *et al.*, 1992; Steinbeck *et al.*, 1998; Savoie *et al.*, 2001).

The sublabral foramen has been previously regarded as normal variation of the anterosuperior labral anatomy (Rao *et al.*, 2003), which we also noted in two investigated shoulder specimens.

The anatomical and MRI appearance of the IGHL complex and the absence of the anterior band on the extra-articular side of the shoulder joint capsule is consistent with previous findings (O'Brien *et al.*, 1990; Kolts *et al.*, 2001; Steinbeck *et al.*, 1998; Palmer *et al.*, 1994; Chandnani *et al.*, 1995; Yeh *et al.*, 1998). The IGHL is the most important stabilizer against anteroinferior shoulder dislocation (Burkart *et al.*, 2002). Reattachment or correction of the permanent plastic deformation of the injured IGHL is essential in operative treatment of anterior shoulder instability.

## CONCLUSIONS

1. The superior shoulder joint capsule is constantly composed of the CHL, CGL and SCL. The CHL has two distinct parts, which has to be considered during intraoperative surgical dissection. Despite its variability, the CGL has macro-and microscopical ligamentous features similar to those of the CHL. Extracapsular macroscopical appearance of the SCL supports the concepts of stress — shielding of the rotator cuff by the stout rotator cable and stress transfer by this loaded ligamentous system.
2. The RI is a multilayered complex of tendineus and ligamentous structures including CHL, CGL, SCL, SGHL, MGHL and anterior fibres of the supraspinatus tendon. Division of the lateral, mediosuperior and medio-inferior parts is clinically relevant to surgical dissection of the different tissue planes in the RI, either in the normal or pathologic state.
3. The *fasciculus obliquus* or the spiral GHL is a consistent, macroscopically recognizable ligament of the anterior shoulder joint capsule. The orientation of the spiral GHL in the tensioned position and its tight connections with the other anterior capsular ligaments indicate that its biomechanical role in shoulder joint stability may be significant.
4. The spiral GHL and the anterior capsular ligaments can be seen on conventional MRI but are best visualized with MR arthrography. The results of this study can be used for clinical evaluation of MR scans.
5. Arthroscopy of the shoulder joint in clinical settings can display the intra-articular part of the spiral GHL in nearly half of the cases. Its normal anatomy should be distinguished from lesions of the subscapularis tendon in the same area.

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## SUMMARY IN ESTONIAN

### Õlaliigese kapsli ja sidemete anatoomia ja selle kliiniline tähendus

Õlaliiges on unikaalse anatoomilise ehituse ja suurima liikumisulatusega inimkeha liiges. Selle aluseks on õlavarreluu pea ja abaluu kaela liigespindade minimaalse luulise piirdega ühendus ning õlavarreluupea ligi kolm korda suurem kõhrepind. Õlavarre liigutustega kaasnevad õlaliigeses kõik kolm erinevat tüüpi liikumist — libisemine, pöörlemine ja veeremine.

Piiratud luulise ühenduse tõttu peavad seda ümbritsevad pehmed koed, peamiselt liigesekapsel, sidemed ja lihased, kindlustama keerulise funktsionaalse tasakaalu õlaliigese liikuvuse ja stabiilsuse vahel. Erinevalt teiste liigeste isomeetrilistest sidemetest on õlaliigese sidemed varieeruva kuju, suuruse ja kinnitumispiirkondadega kapslipaksendid, mis on evolutsiooni käigus kujunenud vastu pidama funktsionaalselt olulistele erisuunalistele tõmbejõududele. Tegemist on komplekse sidemelis-kapsulaarse aparaadiga, mis on omakorda tihedalt seotud õlavarre pöörjalihaste kõõluselise mansetiga. Õlaliigese biomehhaaniliste uuringutega on näidatud, et liigesekapsel ja selle sidemed on tähtsaimad õlavarreluu pea positsiooni säilitamisel õlavarre liigutuste piir- asendites. Samal ajal suruvad õlavarre pöörjalihased õlavarreluu pea abaluu kaela keskmesse, hoides ära ülemääraseid nihkeid liigespindade vahel.

Teades eelpool kirjeldatud anatoomilisi erisusi, saab mõistetavaks, miks on õlaliiges, võrrelduna teiste liigestega, enam vastuvõtlik traumadele ja spordivigastustele. Kroonilisest ülekoormusest tingitud kahjustusi kirjeldati ortopeedilises erialakirjanduses esimesena just õlaliigese piirkonnas.

On teada, et õlaliigese nihestus on sagedaseim, moodustades ligi 50% kõiki-dest keha liigeste nihestustest. Juba varasemate kliiniliste vaatluste põhjal täh-eldati õlaliigese kapsli ja selle sidemete rebendeid õlaliigese korduvate nihestuste korral. Teisalt seostati nende struktuuride patoloogilist armistumist õlaliigese jäikusega. Kaasaegsed anatoomilised ja biomehhaanilised uuringud on kinnita- nud eelnevaid praktilise töö kogemusi ja oluliselt parandanud teadmisi nende struktuuride ehitusest ning funktsioonist. Sageli hõlmavad õlavarre pööraja- lihaste kõõluste vigastused või degeneratiivsed muutused ka kapsli ja sidemete vastavaid piirkondi. Seda on kinnitanud kliinilised uuringud viidates nii isolee- ritud kui kombineeritud patoloogiate esinemisele õlaliigese ebastabiilsuse ja õlavarre pöörjalihaste kõõluste rebenditega patsientidel. Kaasaegse kirurgilise ravi eemärgiks ongi vastavate anatoomiliste struktuuride taastamine.

Õlaliigese haiguste ja vigastuste diagnostika üheks valikuuringuks on kliini- lises praktikas kujunenud kas tavaline või kontrastaine manustamisega magnet- resonantstomograafia (MRT), mis võimaldab kõikide, eriti aga liigeseväliste pehmete kudede täpset hindamist. Kuldseks standardiks liigese sisestest, seejuures



kapsli ja sidemeaparaadi patoloogiate leidmisel peetakse aga õlaliigese diagnostilist artroskoopiat, millele vajadusel järgneb ka ravimenetlus.

Täpne õlaliigese probleemide diagnostika ja ravi nõuab põhjalikke anatoomilisi eelteadmisi. Nii anatoomia kui ka ortopeedia erialakirjanduses on õlaliigese kapslit ja sidemeid võrdlemisi põhjalikult uuritud, arvestades nende tähtsust kliinilises praktikas. Uusi anatoomilisi teadmisi on seejärel rakendatud erinevate struktuuride visualiseerimisel radioloogilisele diagnostikale pühendatud töödes.

Vaatamata sellele näitab varasemate uurimuste ja kaasaegse kirjanduse analüüs, et õlaliigese kapsli ja sidemete kahte kliiniliselt enam tähtsat ja keerukaima ehitusega eesmist ja ülemist osa ei ole veel piisavalt uuritud. Sellele viitavad erinevad või vastukäivad tulemused laipmaterjali anatoomilistes uurimistöödes ning probleemid kirurgilise ravi tulemustes.

Käesoleva uurimuse peamiseks eemärgiks oli parandada teadmisi õlaliigese eesmise ja ülemise kapsli ja sidemete anatoomilisest ehitusest ja keskenduda vähemtuntud või seni veel puudulikult kirjeldatud detailidele.

### **Eesmärgid**

1. Uurida fikseeritud laipmaterjalil õlaliigese ülemise kapsli ja sidemete mikro- ja makroanatoomilisi iseärasusi ning pöörata erilist tähelepanu kliinilises praktikas tuntud rotaatorintervalli (RI) ehitusele.
2. Uurida fikseerimata laipmaterjalil õlaliigese eesmise kapsli ja sidemete anatoomilisi iseärasusi, keskendudes *fasciculus obliquus*'e või nn. spiraalse glenohumeraalsideme (spiraalne GHL) ehitusele.
3. Uurida fikseerimata laipmaterjalil spiraalse GHL-i ja temaga seotud eesmist kapsulaarsete sidemete visualiseerumist magnetresonantstomograafial (MRI).
4. Hinnata patsientidel spiraalse GHL-i liigesesisest nähtavust õlaliigese artroskoopilistel operatsioonidel.

### **Materjal ja meetodid**

Uurimistööks kasutati TÜ Anatoomia Instituudi ja Lübecki Ülikooli Anatoomia Instituudi fikseerimata värskest külmutatud ja fikseeritud laipmaterjali.

Fikseeritud laipmaterjalist prepeareeriti välja 53 õlaliigest (artikkel I ja II). Nendest 34-l uuriti ülemise kapsliosade korakohumeraal (CHL)-ja korakoglenoidaalsideme (CGL) makro- ja mikroanatoomiat. Valgusmikroskoopiaks fikseeriti nimetatud sidemete ja kapsli materjal 4% formaliinis, sisestati paraplasi, lõigati 5 µm paksusteks lõikudeks ja värviti Masson-Goldner järgi resortsiin-fuksiiniga (artikkel I). Ülejäänud 19-l uuriti RI makroanatoomilisi erisusi (artikkel II).

Õlaliigese eesmise kapsli struktuure uuriti kokku 13-l värskest külmutatud laipmaterjali õlaliigesel (artikkel III ja IV). Nendest 6 uuriti ühtse õlavöötme-õlavarre anatoomilise blokina Lübecki Diagnostilise Radioloogia Instituudis MRI uuringul (väljatugevusega 1,5 T), seejuures kolme õlaliigesesse süstiti eelnevalt 15–20 ml 1% kontrastainet magnetresonants (MR) artrograafia läbiviimiseks. Visualiseerimisel kasutati standardprotokolli aksiaalse, sagitaalse ja koronaalse õlaliigese tasapinnaga. Peale MRT uuringut õlaliigese blokid prepareeriti ja makroanatomilisi tulemusi võrreldi MRT ülesvõtetega (artikkel III).

7-l õlaliigesel 13-st tehti makroanatomiline preparatsioon ning eesmise kapsli ja sidemete histoloogiline uuring. Spiraalse GHl-i intraartikulaarse visualiseerumise hindamiseks analüüsiti Helsingis asuvas Diacori haiglas 19 patsiendil tehtud õlaliigese artroskoopilise operatsiooni videosid (artikkel IV).

## Tulemused

1. CHL ja CGL esineb kõigil uuritud õlaliigestel. CHL koosneb ülemisest ja alumisest osast, mis mõlemad algavad *proc. coracoideuse*'lt ja alumine osa lisaks ka CGL-lt. Mõlemad osad kinnituvad makroskoopiliselt eristatavasse semitsirkulaarsesse sidemesse (SCL) õlaliigese kapsli ülemises lateraalses osas. CGL saab alguse *proc. coracoideuse*'lt ja kinnitub supraglenoidaalse kõbrukese piirkonda. SCL esineb kõikidel uuritud õlaliigese preparaatidel kinnitudes ees suure ja väikese kõbrukese ülemistele pindadele ja taga *m. infraspinatus*'e ja *m. teres minor*'i kinnituskoha vahemikule.
2. RI koosseisu kuuluvad CHL, CGL, SCL, ülemine glenohumeraalside (SGHL), keskmine glenohumeraalside (MGHL) ja *m. supraspinatus*'e kõõluse eesmise osa kiud. Vastavalt nende anatoomiliste struktuuride asetsusele, jaotub RI lateraalseks, mediaalseks-ülemiseks ja mediaalseks-alumiseks piirkonnaks. Lateraalse osa moodustavad SCL ja *m. supraspinatus*'e kõõluse eesmised kiud. Mediaalse-ülemise osa moodustavad CHL ja CGL ja mediaalse-alumise osa SGHL ja MGHL.
3. Spiraalne GHl leiti kõikidel prepareeritud õlaliigestel. Side saab alguse infraglenoidaalselt kõbrukeselt ja *m. triceps brachii* kõõluselt, kulgeb põiki eesmise kapsli pindmises kihis ülespoole ja seostub tihedalt alumise glenohumeraalsideme (IGHL) ja MGHL-ga. Ülemises lateraalses osas liitub spiraalne GHl *m. subscapularis*'e kõõlusega ja kinnitub koos sellega väike-seele kõbrukesele.
4. Spiraalne GHl on nähtav kõikidel MR artrograafiaga uuritud õlaliigestel ja ühel kontrastaineta läbiviidud uuringul.
5. Spiraalse GHl-i liigesesisene osa on õlaliigese artroskoopilise operatsiooni ajal nähtav 47,4 %-l juhtudest.

## Järeldused

1. Õlaliigese ülemises kapslis on kolm seda piirkonda tugevdavat sidet — CHL, CGL ja SCL. CHL-i kahte erineva kinnitusega osa peab arvestama laipmaterjali või operatsiooniaegsel kirurgilisel preparatsioonil. CGL on nii makro- kui mikroskoopiliselt struktuurilt sarnane CHL-le. SCL-i ekstraartikulaarne anatoomia toetab senist arvamust, et SCL on pöörajahaste kõõlusele mansetile koormust jaotav ja liigeskapslile ülekandev sidemeline struktuur.
2. RI on keeruline mitmekihilise anatoomilise ehitusega õlaliigese kapsli ala, mille komponentide täpne tundmine on aluseks kirurgilisele preparatsioonile ning nende struktuuride anatoomia eristamisel patoanatoomiast.
3. Spiraalne GHL on makroskoopiliselt eristatav eesmise kapsli side, mille tihe seos MGHL-i ja IGH-iga viitab võimalusele, et ta võib olla biomehaaniliselt oluline õlaliigese stabiliseerija.
4. Spiraalne GHL on MRI-l nähtav koos teiste eesmist kapslisidemetega. MR artrograafia on valikmeetodiks õlaliigese kapsli ja sidemete anatoomia visualiseerimisel. Saadud tulemusi on võimalik rakendada igapäevases kliinilises praktikas MRI ülesvõtete hindamisel.
5. Intraartikulaarne osa spiraalsest GHL-st on artroskoopilistel õlaliigese operatsioonidel nähtav vaid ligi pooltel patsientidest. Nendel juhtudel tuleb seda eristada samas piirkonnas esinevast *m. subscapularis*'e kõõluse vigastusest.

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## **PUBLICATIONS**

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## Education

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1985–1993 University of Tartu, Faculty of Medicine  
1993–1995 Tartu Maarjamõisa Hospital, internship  
1995–2000 Tartu Maarjamõisa Hospital, postgraduate training in orthopaedics  
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## Special courses

1999 AO ASIF Course on Principles of Operative Fracture Treatment, Jurmala, Latvia.  
1999 Basic and advanced course of arthroscopic surgery Kaunas, Lithuania (organized by the French Association of Arthroscopy).  
2001 Kuopio Arthroscopic Shoulder Course, Kuopio, Finland  
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## **Professional employment**

1993–1995	Tartu Maarjamõisa Hospital, internship
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Main fields of research:

- Macro- and microscopic anatomy and clinical relevance of the glenohumeral joint capsule and ligaments.
- Visualization of the MRI anatomy of the glenohumeral joint capsule and ligaments.
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## **Teadustöö**

Peamised uurimisvaldkonnad:

- Õlaliigese kapsli ja sidemete makro- ja mikroanatoomia, selle kliiniline tähendus ja rakendamise võimalused.
- õlaliigese kapsli ja sidemete magnetresonantstomograafiline visualiseerimine ja diagnostiline rakendamine
- 8 teaduslikku artiklit

Organisatsiooniline tegevus:

- Eesti Traumatoloogide ja Ortopeedide Seltsi liige
- Rahvusvahelise Kõhretaastamise Seltsi liige
- AO Alumni Ühenduse liige