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ORIGINAL COMMUNICATION

Innervation Patterns of the Inferior Glenohumeral Ligament: Anatomical and Biomechanical Relevance

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Although the Inferior Glenohumeral Ligament (IGHL) has a well known mechanical and proprioceptive relevance in shoulder stability, the interrelation of the ligament's anatomical disposition/innervation has not actually been described previously. The purpose of the study was to determine the IGHL innervation patterns and relate them to dislocation. Forty-five embalmed and 16 fresh-frozen human cadaveric shoulders were studied. Masson's Trichrome staining detailed the intraligamentous nerve fiber arrangements. The effect on the articular nerves of an anteroinferior dislocation of the shoulder joint and the position of 60° abduction and 45° external rotation was studied dynamically. The axillary nerve provided IGHL innervation in 95.08% of the cases. We saw two distinct innervation patterns originating from the axillary nerve. In Type 1, one or two collaterals diverged later from the main trunk to enter the ligament. Type 2 showed innervation to the ligament provided by the posterior branch for three to four neural branches. In both cases, these branches enter the ligament near the glenoid rim and at the 7 o'clock position (right shoulder). The radial nerve (Type 3 innervation pattern) provided IGHL innervation in 3.28% of the cases. Microscopic analysis revealed wavy intraligamentous neural branches. The articular branches relaxed and separated from the capsule at the apprehension position and stayed intact after dislocation. These results showed a special predisposition to avoid possible denervation and suggested that the neural arch probably remains unaffected after most dislocations. Knowledge of the neural anatomy of the shoulder will clearly help in avoiding its injury in surgical procedures. Clin. Anat. 18:000–000, 2005.

Key words: shoulder anatomy; proprioception; axillary nerve; denervation; joint stability

INTRODUCTION

The Inferior Glenohumeral Ligament (IGHL), or the broad Schlemm ligament (Paturet, 1951), is known as the principal static stabilizer of the glenohumeral joint. Since 1829 when the capsulolabral complex of the shoulder was first described by Flood, many reports have demonstrated its biomechanical relevance (Branch et al., 1995; Levine and Flatow, 2000; Urayama et al., 2001; Burkart and Debski, 2002; Steinbeck et al., 2003). Innervation of the shoulder joint capsule has also been widely described (Gardner, 1948; Testut, 1979; Loomer and Graham, 1989; Williams et al., 1995; Aszmann et al., 1996; Jobe, 2000; Ball et al., 2003). Although a significant number of reports have been published, a con-

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stant pattern of neural contribution to the inferior aspect of the joint cannot be concluded. This could be of vital importance when surgical approaches have to be done (Neer and Foster, 1980; Bryan et al., 1986; Bigliani et al., 1994; Eakin et al., 1998; Matsen et al., 2000; Choi and Ogilvie-Harris, 2002). Innervation of the IGHL is part of the neural arch that determines the proprioceptive properties of the shoulder joint (Guanche et al., 1995). Whether it is injured in shoulder joint lesions or not, it may determine changes in processing the mechanical stimuli signals created by natural movements (Lephart et al., 1994).

The purpose of this work was to identify which neural branches entered the IGHL and to describe their general pattern and their relationships to surrounding anatomical structures. Furthermore, the workings of the joint branches during laboratory-produced subluxations and dislocations of the glenohumeral joint are described.

MATERIALS AND METHODS

Forty-five embalmed (fixed in Cambridge solution) and 16 fresh-frozen adult human cadaveric shoulders (38 left, 23 right) from voluntary donors at the Anatomy and Embryology Unit of the Faculty of Medicine in the Universitat Autònoma de Barcelona were studied. Their ages ranged from 58 to 76 years. The shoulders were grossly normal and none had signs of previous surgery. All the dissections were performed solely by two of the authors (PEG and PY).

A wide deltopectoral approach was used to expose the anterior aspect of the shoulder joint. The fascia between the deltoid and pectoralis major muscle was split to expose the conjoined tendon and clavipectoral fascia. The clavicular insertion of the deltoid was released and then the muscle was retracted laterally. The common origin of the short head of the biceps and coracobrachialis muscles, the conjoined tendon, was released from the coracoid process. Then, the posterior cord of the brachialis plexus was identified and dissected under 3.5× magnification (OPMI-1, Zeiss, Germany). Every branch oriented toward the joint was carefully followed and measured from its origin.

A posterior approach was then made. The deltoid was partially detached from the scapular spine and retracted distally. Special attention was given to the dissection of the quadrilateral space. Identification of the previously dissected capsular nerve branches was done and their anatomical dissection was completed. The length of collateral and terminal branches of the axillary nerve was measured by an electronic caliper (Pro-Max, Fowler; range: 0–150 mm, resolution: 0.02 mm) with the arm in anatomical position.

The subscapularis muscle was then separated from the anterior capsule and a medial-lateral arthrotomy was then performed just anterior to the biceps tendon. Identification of the IGHL and its anterior and posterior band was done. The length of the ligament was measured from the glenoid rim to the humeral neck in the midline of the sagital plane. In addition, the shape of the IGHL humeral insertion of each specimen was recorded. Posteriorly, this lateral border was completely detached and the ligament was pierced with a 21-gauge intramuscular needle, from the point each neural branch was reaching the ligament. Their distances to the limits of the ligament and to the glenoid rim were measured.

Subsequently, four fresh previously dissected specimens were dynamically studied. First, the shoulder joint was positioned in such a way so as to see what happened when it went from a neutral position to 45° of external rotation and 60° of abduction, which is clinically denominated as the apprehension position. Second, as the anteroinferior shoulder dislocation is the most common, the joint was purposely dislocated in that direction to see how the articular neural branches work.

Finally, Masson's Trichrome staining was done on three samples from previously dissected ligaments. The three samples were harvested at the medial-lateral midpoint just posterior to the anterior band and from ligaments with different innervation pattern. The sections (10 μm) were then examined with light microscopy (SMZ-10A, Nikon, Japan; 40× magnification). Identification of the neural fibers and a description of their intraligamentous disposition were finally recorded.

RESULTS

Anatomy of the Inferior Glenohumeral Ligament

The anatomy of the IGHL, as described by O'Brien et al. (1990), was always clearly defined. However, in 7 of 61 cases the anterior band of the IGHL was only a slight thickening of the ligament. In those seven cases, it was well defined only on external rotation. The anterior band was attached to the glenoid rim at the midpoint of the anterior border. It averaged 34 mm (range, 28–46 mm) in length. With the shoulder at 60° of abduction and 45° of external rotation, the anterior band underwent stress and was more clearly defined. The posterior band was only seen in 25 of the cases (40.98%). It was better individualized under abduction and internal rotation.

In 25 of 61 specimens (40.98%) the IGHL was attached to the humeral neck in the form of a collar. In 22 (36.06%) of the cases, the humeral insertion was more inferiorly angulated and thereby configured a v-shaped axillary pouch. In the remaining 14 shoulders (22.95%), the insertion was not as well defined. Therefore it could not be assigned to any of the two different groups.

Main Trunk of the Axillary Nerve

In 52 of 61 cadavers (85.24% of the cases), a branch to the latissimus dorsi exited the posterior cord near the origin of the axillary nerve (±4 mm), whereas in four cases (6.55%), it arose clearly before the origin (range, 8–42 mm). It arose from the axillary nerve itself in another five cases (8.20%) (Fig. 1).

A branch to the teres major muscle was seen less constantly. It originated either from the branch to the latissimus dorsi, the radial nerve, the axillary nerve, or directly from the posterior cord of the brachial plexus. In all specimens, at least one branch to the subscapularis muscle was found. The length of the main trunk of the axillary nerve, measured from its origin in the posterior cord of the brachial plexus to where it divided into two main terminal branches, averaged 46 mm (range, 8–74 mm). It had a constant relationship to the subscapularis muscle (firstly posterior and later superior with respect to the nerve). In 23 specimens, the two main branches of the axillary nerve separated from each other before they passed through the quadrilateral space. In 34 specimens they did it within this topographic structure. In four cases, there were no two clearly defined anterior and posterior branches. In 18 shoulders (29.5%), the trunk of the axillary nerve gave off to the main articular branch of the inferior aspect of the joint.

The shortest distance to the inferior aspect of the glenohumeral capsule was noted at the anteroinferior aspect, slightly anterior to the inferior midpoint of the joint.

Anterior Branch of the Axillary Nerve

The anterior branch of the axillary nerve provided the main innervation to the deltoid muscle, mainly to its two anterior thirds. Also, a branch that pierces the posterior muscle belly arose from this anterior division in all the cases. However, this part of the muscle was consistently (88.52% of the cases) innervated by the posterior branch in our series.

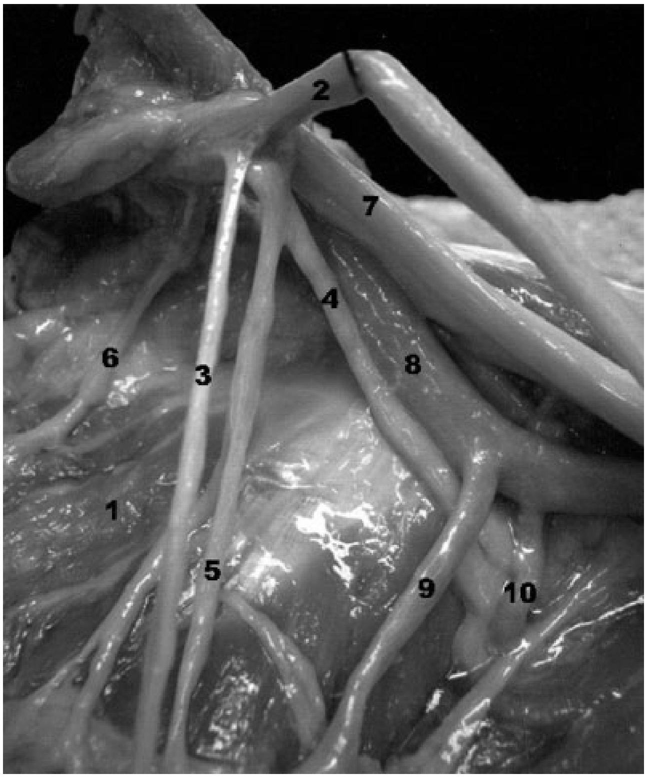

Fig. 1. Anterior view of the left shoulder showing in detail the terminal branches of the posterior cord of the brachial plexus. The axillary nerve is located inferiorly and posteriorly in relation to the axillary artery, and it is crossed anteriorly by the posterior humeral circumflex and the subscapular arteries. 1, subescapular muscle; 2, radial nerve; 3, nerve to latissimus dorsi muscle; 4, axillary nerve; 5, inferior subscapular nerve; 6, superior subscapular nerve; 7, medial cord of the brachial plexus; 8, axillary artery; 9, subscapular artery; 10, posterior humeral circumflex artery.

The anterior branch, as it passed through the quadrilateral space, always laid lateral to the posterior branch of the axillary nerve. Once it passed the quadrilateral space, it diverged laterally around the humeral neck and finally divided into several branches that ended on the deep aspect of the deltoid muscle. A tiny filament pierced the IGHL almost at the humeral border in eight specimens (13.11%).

Posterior Branch of the Axillary Nerve

The posterior branch of the axillary nerve averaged 8 mm in length (range, 1–15 mm) before it divided into two branches. Consistently, it terminated as the branch to the teres minor muscle and the superior-lateral brachial cutaneous nerve (Fig. 2), whereas the muscular branch diverged medially, and the cutaneous division turned laterally to pierce the

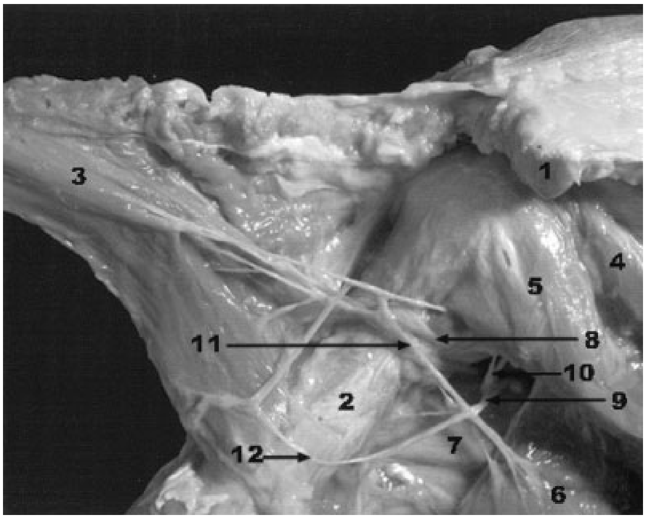

Fig. 2. Posterior view of the left shoulder. The anterior branch of the axillary nerve is seen entering the anterior two-thirds of the deltoid muscle. The nerve of the teres minor and the superior-lateral brachial cutaneous nerve both consistently originate in the posterior branch of the axillary nerve. 1, posterolateral border of the acromion; 2, humeral diaphysis; 3, deltoid muscle partially detached; 4, infraspinatus muscle; 5, teres minor muscle; 6, long head of the triceps brachii muscle; 7, latissimus dorsi muscle; 8, anterior branch of the axillary nerve; 9, posterior branch of the axillary nerve; 10, articular branch to the IGHL; 11, posterior humeral circumflex artery; 12, superior lateral brachial cutaneous nerve.

deep fascia of the deltoid muscle. The division is located on the medial border of its posterior aspect, at an averaged distance of 8.7 cm (range, 6.3–10.9 cm) inferior to the posterolateral corner of the acromion.

In 40 shoulders (65.57%) the posterior branch of the axillary nerve gave off to the main articular branch. In 25 cases (40.98%), the articular branch arose from the branch to the teres minor (at 14 mm averaged from its origin). In another 15 (24.59%) of the cases, it arose just at the beginning of the posterior branch.

The posterior branch had a close relationship to the glenoid rim and the IGHL. It was separated from the IGHL only by a thin layer of fatty tissue.

Innervation Patterns of the IGHL

A consistent innervation pattern of the IGHL was found. Two main dispositions and an additional one of nervous branches to the IGHL were described:

Type 1: In 18 of 61 cases (29.5%), one or two long collaterals branches originated from the main trunk of the axillary nerve at the anterior aspect of the joint. They later diverged posteriorly and laterally upon entering the ligament slightly posterior to the inferior border point. They averaged 28 mm in length (range, 15–43 mm).

Type 2: In 40 of 61 cases (65.57%), the posterior branch of the axillary nerve is the origin point of three or four shorter collaterals (averaged length, 9 mm). They also pierced the IGHL in the same place as in Type 1. In 15 specimens (24.59%), these articular branches arose from the posterior branch itself, whereas, they exited from the branch to the teres minor in the remaining 25 (40.98%) (Figs. 3 and 4).

In both patterns, they entered the ligament mainly at its medial third. Once they reached the capsule, they divided into lateral and medial branches. The width of each branch was 0.75 mm in average. Also, the neural branches in both types were relaxed and separated from the joint at 45° of external rotation and 60° of abduction.

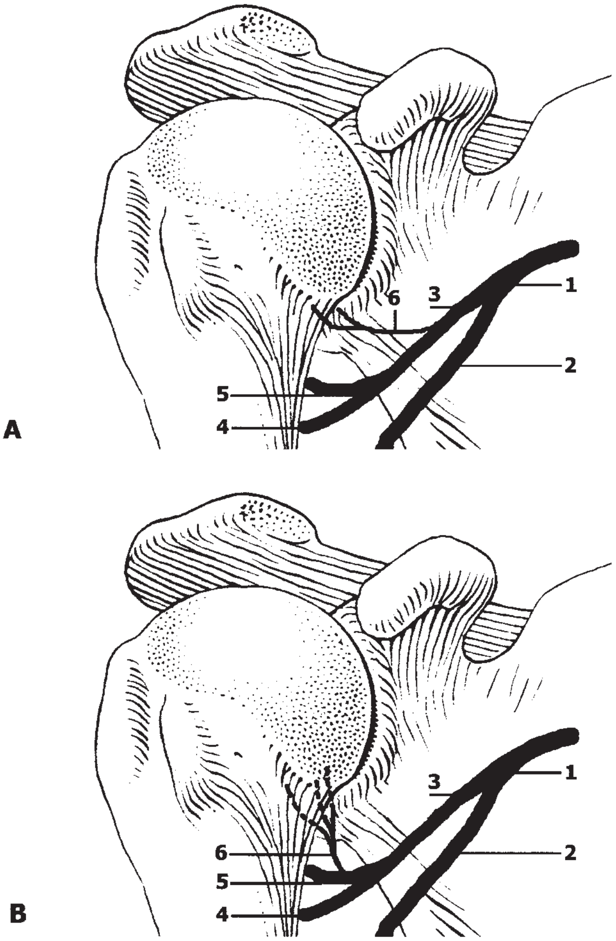

Fig. 3. Schematic diagram of the two main types of innervation of the IGHL. **A:** Type 1 innervation pattern. **B:** Type 2 innervation pattern. 1, posterior cord of the brachial plexus; 2, radial nerve; 3, axillary nerve; 4, anterior branch of the axillary nerve; 5, posterior branch of the axillary nerve; 6, articular branch to the IGHL.

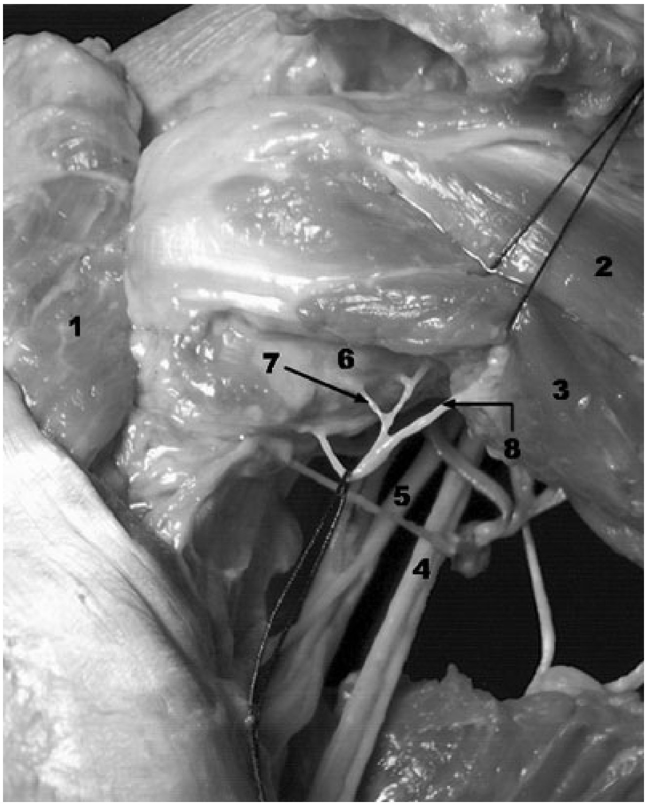

Fig. 4. Posterior view of the left shoulder showing an example of Type 2 innervation pattern. Neural branches to the IGHL arise from the nerve to the teres minor muscle. 1, deltoid muscle partially detached; 2, infraspinatus muscle; 3, teres minor muscle; 4, radial nerve; 5, medial cord of the brachial plexus; 6, IGHL; 7, articular branches to the IGHL; 8, nerve to teres minor muscle.

Type 3: In 2 of 61 cases (3.28%), the most important innervation of the IGHL was provided by the main trunk of the radial nerve (Fig. 5). It gave a gross branch (width, 1.5 mm) in both cases. In one of the specimens, this articular branch left the main trunk of the nerve at 8 mm and the other at 41 mm from its origin. In these two cases, only a very small complementary articular branch was seen arising from the main trunk of the axillary nerve. In one specimen, although carefully dissected, no macroscopic innervation of the IGHL was observed.

Microscopic Neural Disposition of the IGHL

A clear wavy lax pattern of the neural elements was seen in all the specimens stained with Masson's Trichrome, regardless of the macroscopic innervation pattern received (Fig. 6). The neural intraligamentous fibers were parallel and in between collagen bundles. Lax connective tissue surrounded these components.

Neural Disposition During Movement and Dislocation

The articular neural branches, in the four specimens studied, relaxed and separated from the joint at 45° of external rotation and 60° of abduction. Two of the shoulders corresponded to Type 1 innervation pattern and two to Type 2.

When both articular surfaces were completely dislocated in an anteroinferior direction, although moderately tense, the articular neural branches maintained their macroscopic integrity.

DISCUSSION

Findings relative to the innervation of the inferior glenohumeral capsule have been widely variable (Duparc et al., 1997). Since Rüdinger (1857), several descriptions of its neural anatomy have been made. Williams et al. (1995) simply described it as an articular filament arising from the main trunk of the axillary nerve entering the ligament under the subscapular muscle. This might match the pattern that we are describing as Type 1. Loomer and Graham (1989) said that one or two articular branches gave off from the axillary nerve immediately before entering the quadrilateral space. This might match the pattern we are describing as Type 2. However, Ball et al. (2003), found no articular branches that gave off from the posterior branch of the axillary nerve.

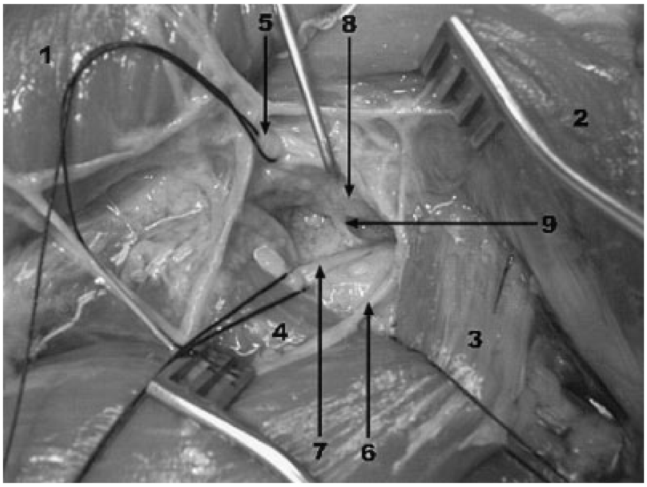

Fig. 5. The main innervation of the IGHL provided by a branch of the radial nerve is shown in posterior view of the left shoulder. 1, deltoid muscle; 2, teres minor muscle; 3, long head of the triceps brachii muscle; 4, teres major muscle; 5, anterior branch of the axillary nerve; 6, posterior branch of the axillary nerve; 7, radial nerve; 8, IGHL; 9, articular branch to the IGHL.

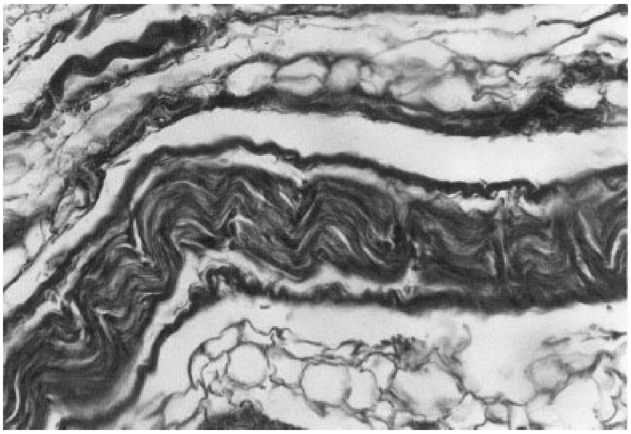

Fig. 6. Cross section (× 40) of the IGHL stained with Masson's Trichrome. A myelinated neural filament is shown with its characteristic wavy pattern. The nerve is surrounded by lax connective tissue.

This is clearly in contrast to our findings and the description of the Type 2 innervation pattern.

Testut and Latarjet (1979) described a big anterior and a thinner posterior articular branch arising from the main trunk of the axillary nerve. They also described filaments exiting from the terminal branches of the axillary nerve, which serve as innervation for the inferior capsule. This might be a combination of our Type 1 and Type 2 innervation patterns. Similarly, Jobe (2000) depicted the axillary nerve as providing an articular branch from the main trunk before entering the quadrilateral space as well as another as the nerve passes through it. Quite similarly, Aszmann et al. (1996) described an articular branch from the anterior division of the axillary nerve. Subsequently, two more articular branches gave off from the anterior branch as it crossed the inferior border of the subscapular muscle. They also mentioned a tiny filament arising from the teres minor branch.

On the other hand, Gardner (1948) described the main articular branch arising shortly after the origin of the axillary nerve in the posterior cord of the brachial plexus. It was also the point of origin for smaller branches that went directly to the anterior aspect of the capsule. The author also mentioned a descending filament coming from the suprascapular nerve upon entering the anterior aspect of the joint. As far as we know, this was the first report in medical literature that mentioned the possible innervation of the anterior inferior capsule by the radial nerve. Nevertheless, he could not clearly demonstrate it. The main innervation of this aspect of the joint was undoubtedly provided by a radial nerve articular branch in 2 of the 61 cases in our series. This particular innervation pattern is defined as Type 3.

The capsulolabral complex of the shoulder joint was first described by Flood (1829). More recently, its current anatomical conception and hammocklike appearance has been well characterized (O'Brien et al., 1990). Bankart (1938) stated that disruption and detachment of the anterior-inferior capsule from the glenoid was mainly responsible for on-going instability after shoulder dislocation. Now, the key role of the IGHL in shoulder joint stability is widely accepted (Turkel et al., 1981; Branch et al., 1995; Steinbeck et al., 1998; McMahon et al., 1999; Jobe, 2000; Levine and Flatow, 2000; McMahon et al., 2001; Urayama et al., 2001; Burkart and Debski, 2002). Therefore, many surgical procedures advocate its reconstruction to recover normal joint stability (Neer and Foster, 1980; Bigliani et al., 1994; Matsen et al., 2000; Choi and Ogilvie-Harris, 2002; Lephart et al., 2002; Gill and Zarins, 2003).

In the current study, we tried to define the neural anatomy of the IGHL. Knowledge of its anatomy and relationships will clearly help in avoiding its injury in surgical procedures (Neer and Foster, 1980; Bryan et al., 1986; Stanish and Peterson, 1995; Burkhart et al., 1996; Eakin et al., 1998; Ho et al., 1999; Perlmutter, 1999; McFarland et al., 2001, 2002; ; Jerosh et al., 2002; Gill and Zarins, 2003). What is of further significance is the lax anatomical situation of these innervating branches, as defined through microscopic examination. It helps in better understanding of why after a capsulolabral reconstruction the neural arch might be completely recovered (Lephart et al., 1994; Guanche et al., 1995; Lephart et al., 1997; Myers and Lephart, 2002; Steinbeck et al., 2003).

The present study showed two main different patterns of innervation provided by the axillary nerve. This has not previously been described. We have also proven that innervating branches of the IGHL relax and separate from the capsule with external rotation and abduction maneuvers. This coincided with previous reports (Loomer and Graham, 1989; Jerosch et al., 2002). This fact may be of critical importance if proprioception is to be kept intact after surgical procedures that involve inferomedial exposures, that is, inferior capsular shifts (Loomer and Graham, 1989). Furthermore, we have seen that the articular neural branches to the IGHL remained macroscopically intact after shoulder dislocation. To summarize, innervation of the IGHL has a predisposition to stay intact regardless of the wide range of motion of the glenohumeral joint. This is true, even after a dislocation or after an anteroinferior labrum disruption. To our knowledge this is also the first work that clearly describes two cases in which the main innervation of the IGHL is provided by the radial nerve.

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