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Sensory innervation of the human shoulder joint: the three bridges to break

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Background: Painful shoulders create a substantial socioeconomic burden and significant diagnostic challenge for shoulder surgeons. Consensus with respect to the anatomic location of sensory nerve branches is lacking. The aim of this literature review was to establish consensus with respect to the anatomic features of the articular branches (ABs) (1) innervating the shoulder joint and (2) the distribution of sensory receptors about its capsule and bursae.

Materials and methods: Four electronic databases were queried, between January 1945 and June 2019. Thirty original articles providing a detailed description of the distribution of sensory receptors about the shoulder joint capsule (13) and its ABs (22) were reviewed.

Results: The suprascapular, lateral pectoral, axillary, and lower subscapular nerves were found to provide ABs to the shoulder joint. The highest density of nociceptors was found in the subacromial bursa. The highest density of mechanoreceptors was identified within the insertion of the glenohumeral ligaments. The most frequently identified innervation pattern comprised 3 nerve bridges (consisting of ABs from suprascapular, axillary, and lateral pectoral nerves) connecting the trigger and the identified pain generator areas rich in nociceptors.

Conclusion: Current literature supports the presence of a common sensory innervation pattern for the human shoulder joint. Anatomic studies have demonstrated that the most common parent nerves supplying ABs to the shoulder joint are the suprascapular, lateral pectoral, and axillary nerves. Further studies are needed to assess both the safety and efficacy of selective denervation of the painful shoulders, while limiting the loss of proprioceptive function.

Level of evidence: Anatomy Study; Literature Review

Keywords: Anatomy; denervation; pain; shoulder joint; joint innervation; nerve; review

Painful shoulders (PS) create a substantial socioeconomic burden and significant diagnostic challenge for shoulder surgeons.[9,25,32,50,53] Almost 20% of the general population suffers from shoulder pain in their lifetime, making it the third most common musculoskeletal complaint.[15,25] PS also lead to impairments in patients' ability to work or perform activities of daily

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living.[20] Management of PS has been estimated to account for 4.5 million physician visits and $3 billion (£2.3bn; €2.6bn) in financial burden each year in the United States alone.[8,32,53] Ketola et al[27] reported that up to 20% of patients had persistently PS after subacromial surgery, and no significant benefit has been demonstrated after subacromial decompression for PS.[6,38]

Prior reports have found that the highest density of nociceptors in the shoulder lies in the anterosuperior portion of subacromial bursa (SAB).[19,21,24,45] With this information in mind, local nerve blocks[37,41-43] and stimulation systems[56] have been trialed for the treatment of transient PS. More permanent techniques, including partial anterior shoulder denervation, involving the articular branches (ABs) of the lateral pectoral nerve (LPN) have been demonstrated to provide pain relief in 92% of patients with persistently PS.[10,11] Despite the success of this series, recent anatomic studies have demonstrated that several different parent nerves contribute to nociceptive shoulder innervation.[31,48] Therefore, one might reasonably advocate for a denervation strategy that addresses all parent nerves (suprascapular, axillary, LPN) in an effort to completely eliminate persistent shoulder pain.[10]

Even with the recently published anatomic studies, there continues to be a lack of consensus with respect to the anatomic location of ABs about the shoulder. Furthermore, the distribution and course of these branches does not seem to be reproducible.[31] We hypothesize that the efficiency of shoulder denervation could be improved once a consensus description of the distribution of nociceptors and articular nerve branches has been defined.

The aim of this literature review was to establish consensus with respect to (1) the anatomic features of the ABs innervating the shoulder joint and (2) the distribution of sensory receptors about its capsule and bursae.

Materials and methods

The aim of this study was to collect and review international literature describing the ABs of the shoulder joint, as well as the sensory branches to its capsule, ligaments, and bursae. A literature search was performed using 5 different databases: Ovid Medline, Ovid Embase, Scopus, Web of Science, and Cochrane. Articles from 1945 to 2019 were included, and the search was performed using the Medical Subject Headings and keywords. The search was limited to English language literature. The terms shoulder joint, capsule, denervation, shoulder innervation, nerve, articular branch, sensory receptors, capsule, ligament, and anatomy were used in various combinations with "AND" and "OR" to assist in review. Because of the limited historical timeframe that can be searched via these engines, references from the existing literature were also queried. The figures of dissections and descriptions of the course of each branch were also reviewed. A Preferred Reporting Items for Systematic Reviews and Meta-Analyses flowchart was created to illustrate the inclusion and exclusion criteria (Fig. 1).

Review of literature

Quality of studies

Our electronic search yielded a total of 876 studies. After applying inclusion and exclusion criteria, articles underwent full-text evaluation. A total of 13 articles related to shoulder sensory receptors and 22 related to ABs were included in the review. A summary of the search strategy is outlined in Figure 1.

Sensory receptors

Sensory receptors include mechanoreceptors (Ruffini, Pacinian, and Golgi corpuscles) and nociceptors (free nerves endings). Both types were found in the shoulder joint capsule, its bursae, and its ligaments.

Capsule

The present literature, including immunohistochemical studies, would suggest that the density of sensory receptors about the shoulder varied based on anatomic location.[21] The highest density of noci- and mechanoreceptors has been identified in the antero- and posterosuperior portions of the glenohumeral (GH) capsule and at the superior aspect of the capsulolabral junction. Hashimoto et al[21] also recognized that the anteroinferior GH capsule is rich in mechanoreceptors. Witherspoon et al[57] further described this topographic map when they identified a mechanoreceptor gradient, with a concentration that peaked superficially and decreased with tissue depth. Finally, with respect to the labrum, the highest density of mechanoreceptors was found anteroinferiorly and at a junction between the capsule and the glenoid rim.[57] No studies specifically addressed nociceptor distribution; however, multiple stated that these receptors were commonly found in the peripheral half of the glenoid labrum.[19-52]

Ligaments

Guanche et al[19] noted that the 3 parts of the anterior GH ligament are supplied by sensory receptors. They also found both mechano- and nociceptors in 3 GH ligaments. The coracoacromial (CA) ligament, however, was described as aneural. Konttinen et al[28] demonstrated that connective tissue neighboring CA ligament was richly innervated with a high density of both mechano- and nociceptors. The density of mechanoreceptors was equal among all coracoclavicular ligaments and acromioclavicular joint ligaments.[52] Interestingly, nociceptor density in the CA and clavicular ligaments was increased in

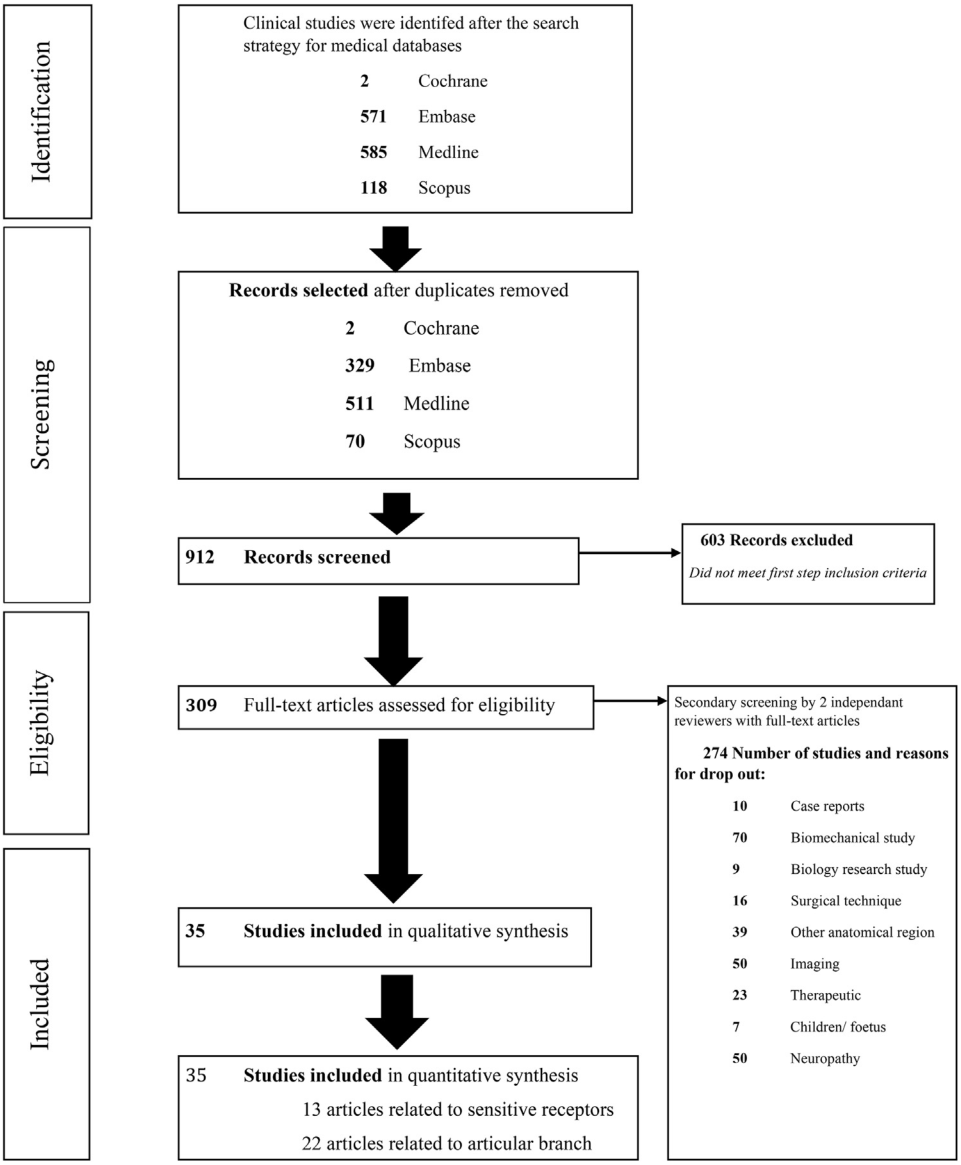

Figure 1 Summary of search strategy (Preferred Reporting Items for Systematic Reviews and Meta-Analyses flowchart) for relevant studies on sensory innervation of the shoulder joint.

patients with rotator cuff disease.[47] Snow et al[46] reported on the presence of nociceptors and the simultaneous absence of mechanoreceptors in the transverse humeral ligament (THL).

Subacromial bursa

The SAB is the structure in the shoulder with the highest density of nociceptors.[26,27] In 1996, Ide et al[24] described 3 distinct areas within the SAB with the highest density of nocireceptors. The aforementioned areas were the subdeltoid portion, the arch under the CA ligament, and greater tuberosity; the posteromedial portion of the SAB was found to be less densely innervated. Tomita et al[48] were the first to identify a positive correlation between the density of the sensory receptors in the SAB and the severity of rotator cuff disease. Mechanoreceptors have also been found under the CA ligament and about the great tuberosity,[19] albeit with decreased frequency.

Long head of the biceps tendon

Guanche et al[19] reported on the presence of nociceptors in the long head of the biceps tendon (LHBT), the highest density being found at its proximal insertion. The density decreased progressively from proximal to distal until one reached the musculotendinous junction.[3,25] Mechanoreceptors have also been found in the central portion of the LHBT.[21]

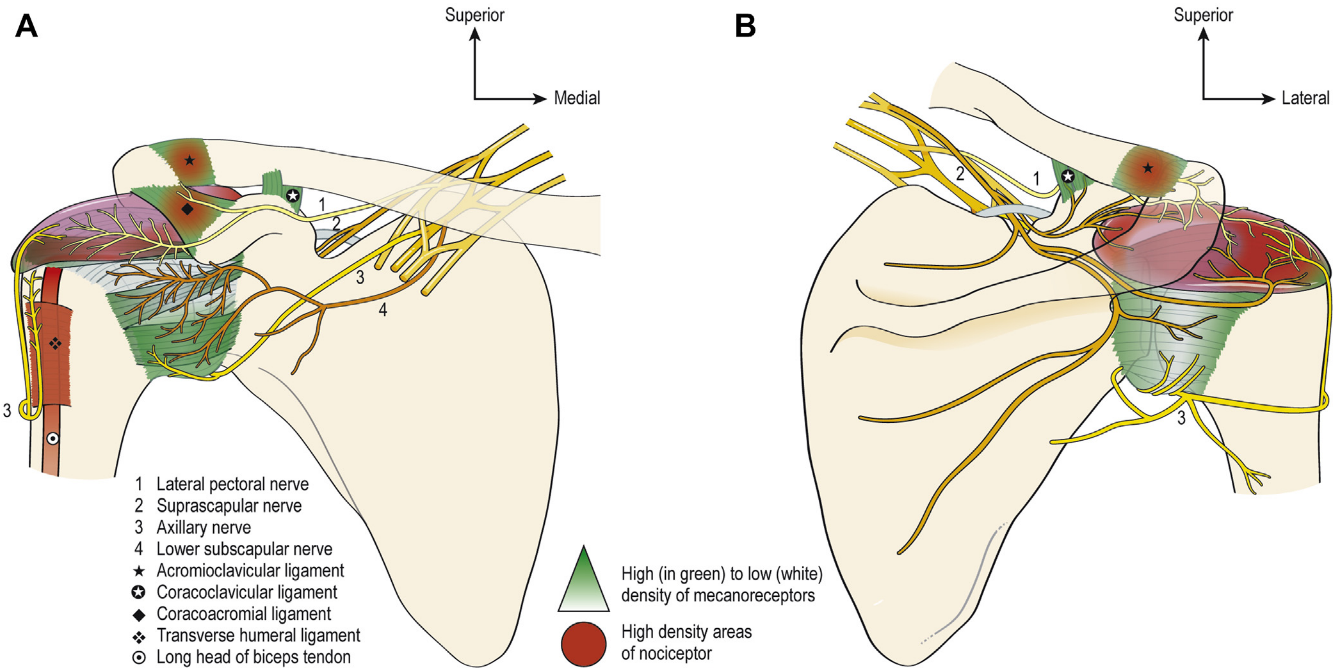

Figure 2 Schematic diagram of sensory innervation of the shoulder joint. (**A**) Anterior view; (**B**) posterior view.

Acromioclavicular joint

Vangsness et al[52] noted the presence of mechanoreceptors in the acromioclavicular joint; however, no paper studying acromioclavicular joint nociceptors could be identified.

Nerves and articular branches

The articular nerve branches innervating the shoulder joint were found to arise from the suprascapular (SSN), LPN, lower subscapular (LSN), radial, and axillary (AN) nerves (Fig. 2; Table I).

Suprascapular nerve

Gardner[16] described a lateral AB of the SSN in 1948, which provided innervation to the coracoclavicular ligaments and terminated its course in the superior aspect of the GH capsule. Aszmann and Dellon[4] described this branch as a medial AB innervating the coracoclavicular and coracohumeral ligaments and SAB. They also identified distal and lateral ABs terminating within the posterior joint capsule. Vorster et al[54] provided data to support this medial AB course and described the course of a new branch, splitting off from the parent nerve just proximal to the scapular neck and running on the scapula deep to the supraspinatus before entering the infraspinatus near its tendon. Ebraheim et al[13] confirmed that the medial AB turns laterally along the base of the coracoid process and terminated in the acromioclavicular joint and SAB. They also described a second branch running laterally proximal to the infraspinous fossa and entering the posterior aspect of the capsule deep to the infraspinatus. Eckmann et al[14] classified ABs with respect to the spinoglenoid notch (superior and inferior). These ABs were reported to course laterally in the supraspinous (superior branch) and infraspinous (inferior branch) fossae of the scapula to innervate the posterior GH capsule, SAB, and posterior fascia of the head and neck of the humerus. The authors did not describe a discrete anatomic area of innervation in their paper.[14] In 2019, Laumonerie et al[31] described a lateral subacromial branch, which arose from the SSN distal to the suprascapular notch and terminated over the supraspinatus muscle in the medial portion of the SAB and the acromial insertion of the acromioclavicular ligament. This study elucidated previously undescribed anatomy of the SSN and its 3 distinct AB courses: 2 subacromial branches (medial and lateral) and 1 posterior GH branch to the shoulder joint. This arrangement, allowing for bipolar innervation of the SAB, was consistent with the bipolar distribution of the nociceptors in the medial and lateral part of the SAB described by Ide et al.[24]

Axillary nerve

Gardner[16] initially described the ABs as arising from 3 sites: the main trunk, as well as the anterior and posterior divisions. After the AN entered the quadrangular space, 1 or 2 ABs take off from the main trunk. These ABs traveled with the anterior circumflex humeral artery and coursed

Table I Summary of studies describing parent nerves that provide branches to the shoulder joint

Author and year	No. shoulders	Axillary nerve	Suprascapular nerve	Lower scapular nerve	Lateral pectoral nerve
Gardner, 1948[16]	7	×	×	×	×
Wrete, 1949[58]	5	×	×	×	
Horiguchi, 1980[23]	6		×		
Loomer and Graham, 1989[33]	12	×			
Ajmani, 1994[1]	NA		×		
Aszmann et al, 1996[5]	25	×	×	×	×
Duparc et al, 1997[12]	32	×			
Zhao et al, 2001[59]	40	×			
Akita et al, 2002[2]	125				×
Gelber et al, 2006[17]	61	×	×		
Uz et al, 2007[51]	30	×			
Loukas et al, 2009[34]	100	×			
Vorster et al, 2008[54]	31		×		
Porzionato et al, 2012[40]	802*				×
Ebraheim et al, 2011[13]	12		×		
Dean, 2013[9]	NA	×	×	×	×
Nasu et al, 2015[36]	20	×	×		
Nam et al, 2016[35]	43				×
Eckmann et al, 2017[14]	21	×	×		×
Seo et al, 2018[44]	18	×			
Laumonerie et al, 2019[31]	37		×		
Tran et al, 2019[49]	15	×	×	×	×

NA, not available.
* Literature review.

between the tendons of the subscapularis and latissimus dorsi muscles. At the medial border of the humerus, the ABs coursed superiorly, deep to the tendon of the subscapularis.[49] Before they reached the capsule, each split into 2 main branches[5] that themselves ramified into small nerve bundles within the joint capsule. The medial branch mainly supplied the scapular aspect of the anteroinferior capsule and portions of the axillary recess, whereas the lateral branch innervated the humeral portion of the anterior capsule.[9] Duparc et al[12] described an additional 1-4 inconsistent ABs innervating the anteroinferior capsule. The first AB arised between the subscapularis muscle and the anterolateral border of the tendon of the long head of the triceps brachii, whereas the other AB arised distal to it. The anterior division of the AN gave off the first AB that terminated in the anteroinferior capsule.[34,59] Nasu et al[36] found an AB ascending on the lateral aspect of the humerus to terminate within the lateral edge of subacromial and subdeltoid bursae, and distal portion of the LHBT.[36,45] Tran et al[49] later described 2-3 ABs emerging from the anterior division that terminate in the THL. After emerging from the quadrangular space, the posterior division of the AN gave off a branch to the teres minor from which 1-4 ABs result.[14,17] These ABs entered the medial third of the inferior GH ligament and divided into lateral and medial branches to innervate the posteroinferior capsule.[14,17]

Lateral pectoral nerve

In 1948, Gardner[16] described a small AB from the LPN innervating the anterosuperior capsule of the shoulder arising between the coracoid process and the acromioclavicular joint. Aszmann et al[5] detailed the course of the nerve. The LPN crossed the superomedial side of the coracoid process and sent small branches to the coracoclavicular ligament. Then the LPN coursed laterally and divided into 2 main branches on the superior side of the coracoid process between the CA and coracoclavicular ligaments, respectively. The first branch supplied the anterior acromioclavicular joint; the second branch descended underneath the CA ligament to innervate the SAB.[2,5,14,35,49] Nam et al[35] found that this second branch entered the shoulder after passing beneath the base of the CA ligament; the entry point was identified at 4.6 cm medial to the lateral tip of the acromion. This AB innervated the anterosuperior portion of the GH capsule. In one case, Tran et al[49] found that the LPN gave off another AB that terminated in the anteroinferior GH joint capsule.

Lower subscapular nerve

In the aforementioned study, Gardner[16] described a GH AB of the subscapular nerve arising from the posterior cord and descending obliquely across the ventral surface of the subscapularis muscle. When it reached the tendon of this

Table II Innervation of anatomic regions of the shoulder joint by parent nerves

	Anterior capsule		Posterior capsule		Subacromial bursa		Subdeltoid bursa	Long head of the biceps tendon	Acromioclavicular joint
	Superior	Inferior	Superior	Inferior	Anterior	Posterior			
Axillary nerve		*		*	*	*	*	*	
Suprascapular nerve			*		*	*			*
Lower subscapular nerve	*							*	
Lateral pectoral nerve	*	*			*				*

muscle, it divided into several smaller branches. One or two of those anastomosed with the branches from the AN to innervate the long head of the biceps tendon. A few others pierced the tendon of the subscapularis muscle and entered the anterior capsule.[16,58] In 1996, Aszmann et al[5] described ABs arising from the more lateral of the 3 LSN branches. Tran et al[49] detailed the course of these branches. The authors demonstrated that the most superior nerve to the subscapularis gave off 1-2 ABs that course with the subcoracoid branch of the axillary artery, along the superior border of the subscapularis, deep to the coracoid process. At the margin of the glenoid fossa, the ABs coursed deep to the subscapularis to innervate the anterosuperior quadrant of the GH joint.

Radial nerve

In the classic description, the radial nerves did not participate to the shoulder innervation.[5,49] However, Gelber et al[17] found that the radial nerve's main trunk gave off a branch to the inferior GH ligament in 3.3% of shoulders.

Discussion

The present literature reviewed summarized all described ABs innervating the shoulder joint. The resulting frequency map of AB and sensory receptors provided an anatomical basis with which to design targeted denervation (Table II, Figs. 2 and 3).

There were several identifiable limitations of the reviewed literature. Providing a complete and detailed description of shoulder innervation has long been a challenge to the anatomist. For this reason, few studies have comprehensively described the anatomic features of each of the ABs. This dearth of precise data provided a strong indication for a more precise and standardized description of the observations and measurements in dissection studies. However, the low number of specimens in each study (Table I), the different methods of dissection, and their inherent high risk of elongation or section of the small ABs could also contribute to the variability in the number and courses of described ABs. Furthermore, the specific topography of the nociceptors about the GH capsule

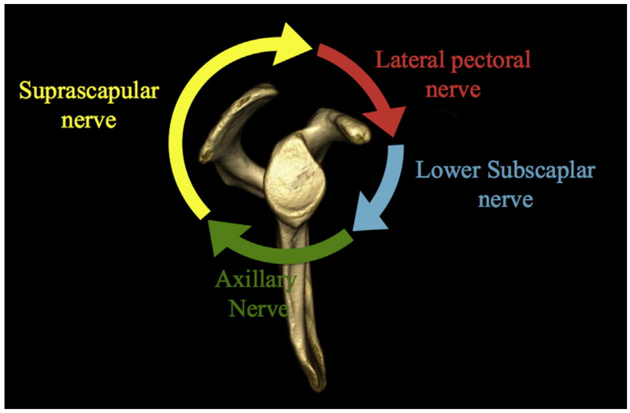

Figure 3 Summary of the innervation of quadrants of the shoulder joint.

remained unknown, which limited our understanding of potential pain generators.[20]

Innervation of the shoulder joint was provided by the SSN, AN, LPN, and LSS (Fig. 3; Table II), which is in accordance with Hilton's law.[22] The SSN was found to be the greatest contributor to overall shoulder innervation.[31] It was found to provide sensory innervation to the posterior GH capsule, SAB, CA, and acromioclavicular ligaments.[30] The AN was also found to innervate smaller areas involving the inferior portion of the anterior and posterior GH capsule.[48] The innervation pattern of the anterior shoulder joint was found to be quite a bit more complex (Fig. 2; Table II). Although the medial portion was found to be primarily innervated by muscular branches of the LSN,[15,49,58] the lateral aspect of the capsule is supplied by ABs arising directly from the AN.[36] The LPN also innervated the anterosuperior quadrant of the shoulder including the anterior edge of the SAB, the CA ligaments, and the GH capsule.[4,16,35]

Previous studies describing the neuroanatomical distribution of sensory receptors highlighted the proprioceptive role of the capsule and ligaments about the GH joint.[17,19,21,28] The mechanoreceptors were most concentrated at the medial and lateral insertions of the anterior capsule, with relative scarcity of these receptors in the

Figure 4 The common innervation in the shoulder allowed painful diffusion from injured triggers (rotator cuff, glenohumeral joint) to the identified pain generators (subacromial bursa, the coracoacromial ligament, and the long head of the biceps tendon) areas by the 3 nerve bridges (axillary, suprascapular, and lateral pectoral nerves).

capsule's mid region.[19,21,29] Our review found that the receptor distribution also highlighted the important role that the LHBT, labrum, and inferomedial capsule play in shoulder stability, specifically with respect to the musculoligamentous protective reflex.[19,29,39] Nociceptors are primarily identified in the superior quadrant of the shoulder, including the SAB, GH, CA, and coracoclavicular ligaments, and the proximal portion of the LHBT (and the THL).[19,24,29,45] The SAB is the area of densest, tripolar nociceptive innervation.[45] These 3 nociceptive poles may correspond to the location of the lateral/medial subacromial branches of the SSN (ie, lateral and medial poles) and to the ABs of the LPN (anterior pole);[24] fine ABs from the AN may also participate to the innervation lateral pole of the SAB.[36,45]

Dellon et al[10,11] previously proposed a partial anterior shoulder denervation involving the ABs of the LPN via a single incision over the coracoid for patients with anterosuperior PS. In a clinical series of 12 patients published in 2004, the authors[10,11] reported a mean decrease in visual analog scale pain scores from 8.5 to 1.8, in addition to an absence of short-term complications. However, Wilhelm[55] pointed out that innervation of the anterosuperior quadrant of the shoulder is complex and cannot be reduced to the LPN alone. The subacromial branches from the SSN and the fine ramifications from the AN to the LHBT (and the THL) and SAB have a well-established, reproducible course within the most nociceptor-rich portion of the shoulder.[31,36] Total shoulder denervation is unrealistic as almost all of the ABs innervating the capsule are too fine to be identified.[5,16,58] Given the data summarized in this review, selective shoulder denervation with a focus on branches of the LPN, SSN, and AN would be most feasible and most likely to provide clinically relevant pain relief.

Lessons learned

Data summarized herein have allowed for identification of anatomic pain generators, defined as those areas with the highest nociceptive density, including the SAB, CA and coracoclavicular ligaments, LHBT, and THL. They also demonstrated that these pain generators were innervated by the same nerves that innervated anatomic regions at particularly high risk of injury (rotator cuff and GH joint): SSN, LPN, and AN (Fig. 3). Tomita et al's[48] and Tamai et al's[47] studies also demonstrated an increasing density of nociceptors in the SAB and CA ligaments in patients with rotator cuff injuries. On the basis of their findings, as well as the reviewed literature, we propose the existence of a ''nerve bridge'' principle (Fig. 4). We posit that these nerves may transmit stimulation from the injured trigger areas to areas rich in nociceptors, thereby creating (or nociceptor sensitization) secondary pain sites away from the primary injured structure.[18,28,29] This may explain typical clinical presentations of patients with rotator cuff tears who present with pain over the CA ligament. Selective denervation would ideally spare the medial and lateral insertions of the GH capsule where the majority of mechanical receptors are located as these receptors participate in dynamic stabilization via the musculoligamentous protective reflex.[19,29,39] Overly aggressive denervation of the GH capsule and ligaments could, therefore, worsen instability and/or accelerate degenerative arthritis.[19,29,39]

Future directions

The concept of nerve connectivity between pain generator areas and areas rich in nociceptors, as described above, leads us to believe that ''Breaking the three nerve bridges'' may be a solution to treat persistently PS (Fig. 4). The pain generators and their parent nerves (AN, LPN, SSN) should be the target of treatment as well as the injured trigger areas (ie, rotator cuff or GH joint). A selective denervation focused on the nociceptive branches arising from the SSN, LPN, and AN, which could neutralize the pain generator areas: SAB, AC and coracoclavicular ligaments, and the LPB. Furthermore, this technique would maintain the integrity of mechanoreceptors primarily located in the anterior capsule and GH ligaments.[19,29,39] This selective denervation could be considered as a complimentary treatment strategy, or alternative, to currently use the arthroscopic rotator cuff repair or the Latarjet procedure.[7,30]

Conclusion

The SSN, LPN, AN, and LSN were found to supply ABs to the shoulder joint. The highest density of nociceptors and mechanoreceptors was identified in SAB and anterior GH capsule/ligaments, respectively. Further studies are needed to assess both the safety and efficacy of selective denervation of the PS, while limiting the loss of proprioceptive function.

Disclaimer

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