Shoulder joint position sense after thermal, open, and arthroscopic capsulorrhaphy for recurrent anterior instability

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Identifying the optimal surgical treatment for recurrent, anterior glenohumeral instability remains a challenge. Our purpose was to compare shoulder joint position sense among open, arthroscopic, and thermal capsulorrhaphy patients after repair of recurrent anterior instability and to compare these patients to healthy, control subjects. Sixty-seven adults (45 post-surgical patients, 22 controls) volunteered to participate in the study. We evaluated both the surgically repaired and contralateral shoulders of 45 capsulorrhaphy patients (28 men, 17 women) and compared their results with the normal bilateral shoulders of 22 age-matched controls (11 men, 11 women). Accuracy of joint position sense was quantified via passive reproduction of target positions set at 60% and 90% of each subject's maximum passive external rotation (ER_{max}). We observed no significant differences in joint position sense between the repaired shoulders and the contralateral normal shoulders of all groups of capsulorrhaphy patients. Open and thermal capsulorrhaphy patients demonstrated significantly better ($P \leq .05$) repaired-limb joint position sense ($5.4° \pm 3.3°$ and $5.6° \pm 3.3°$, respectively) than arthroscopic patients ($9.2° \pm 3.7°$) and control subjects ($8.1° \pm 4.0°$). These results indicate that joint position sense was similar in the repaired shoulders and uninjured shoulders of each group of capsulorrhaphy patients. The mechanism responsible for heightened position sense in open and thermal capsulorrhaphy patients is unknown, but may result from capsular retensioning and muscular scarring. The long-term implications of this outcome deserve further attention. (J Shoulder Elbow Surg 2008;17:389-394.)

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1058-2746/2008/$34.00
doi:10.1016/j.jse.2007.11.015

The optimal surgical treatment for managing recurrent, anterior glenohumeral instability continues to be debated. While open capsular shift techniques have been considered the gold standard as they limit recurrent instability to 1% to 10%,[5,25,32,36] arthroscopic techniques have rapidly evolved and have recently demonstrated comparable success rates.[3-5,9,28] Initial reports of thermal capsulorrhaphy procedures demonstrated favorable outcomes;[7,8,17] however, recent reports[15-17,37,41] have identified substantial complications following denaturation of collagen, including increased tissue extensibility,[37,41] chondrolysis,[24,30] and arthrofibrosis.[10,30] Reported failure rates for thermal capsulorrhaphy have been high, ranging from 4% to 26% in patients with anterior instability[8,14] and from 36% to 64% in patients with multidirectional instability.[6,14] To date, thermal capsulorrhaphy has not withstood the scrutiny of long-term follow-up evaluation, as clinical outcomes have diminished over time.[6,18]

The chief goal of each glenohumeral stabilization technique is to restore joint function through repair of mechanical instability. However, the effects that each technique has on the somatosensory aspects that enhance joint stability must also be considered. Numerous authors[23,27,31,40] have hypothesized that a neurofeedback mechanism exists between afferent mechanoreceptors and muscular stabilizers, and that traumatic or atraumatic disruption of this mechanism inhibits the normal, reflexive joint stability essential for normal shoulder function. Indeed, patients with anterior instability have shown impaired proprioception in their unstable shoulders compared to their contralateral, uninjured limbs.[23] Several authors have documented that surgical restoration of normal, glenohumeral capsular tensioning may combat the problem of functional instability by minimizing damage to mechanoreceptors.[20,21,23,31] However, the optimal type of capsular reconstruction that accomplishes this goal remains unknown.[31]

Many studies have examined shoulder proprioception after arthroscopic and open capsulorrhaphy,[2,19,23,33] but no single study has compared groups of thermal, open, and arthroscopic capsulorrhaphy patients. The purpose of our study was to compare shoulder joint position sense among these surgical groups and against healthy, age-matched controls.

Considering that thermal capsulorrhaphy is known to cause significant collagen denaturation, and result in a high rate of postoperative failure,[15-17,37,41] we hypothesized that joint position sense would be diminished in thermal capsulorrhaphy patients versus patients treated with other arthroscopic and open techniques. We also hypothesized that surgically-repaired shoulders would demonstrate comparable joint position sense to the normal, contralateral shoulders and to control subjects' normal shoulders.

MATERIALS AND METHODS

Sixty-seven adults (39 men, 28 women; mean age, 23.7 ± 6.8 years) participated in this study, including 45 postsurgical patients and 22 control subjects. The control group included 22 healthy subjects with no history or clinical evidence of shoulder pathology. The inclusion criteria for postsurgical patients were a history of recurrent anterior shoulder instability, no history of concomitant impingement or rotator cuff pathology, full discharge from postoperative rehabilitation, and physician clearance for return to activity and/or employment. Because of the difficulty of subject recruitment, we evaluated patients referred from 15 surgeons. While this approach was not a randomized controlled trial, it provided a broad cross-section of patients who represented the current application of capsulorrhaphy techniques among different surgeons.

Fifty-four patients were referred by their surgeons after repair of the anteroinferior capsulolabral complex due to recurrent, anterior shoulder instability; 45 of these patients (28 men, 17 women) met the inclusion criteria. Of the 9 patients that were excluded from the analysis, 4 had multidirectional instability, 1 had a concomitant rotator cuff repair, and 4 had bilateral shoulder surgery, and, thus, did not have a normal limb for comparison.

The decision to perform open, arthroscopic, or thermal stabilization was made by the treating surgeon after thorough examination in the clinic and under anesthesia to determine the specific shoulder pathology. An open capsulorrhaphy was performed if the patient had either a history of traumatic dislocation, a patulous anteroinferior joint capsule, and/or if a substantial bony lesion was present. An arthroscopic capsular plication was performed if the patient had sufficient and viable capsular tissue and/or an isolated Bankart lesion. Isolated thermal capsulorrhaphy was performed if the patient had capsular laxity or was performed in conjunction with arthroscopic Bankart repair when a labral lesion was present. An arthroscopic approach—whether for capsular plication or thermal capsulorrhaphy—was preferred for active and overhead patients. Concomitant labral pathology at time of surgery included 30 patients with Bankart lesions (66%) and 8 with SLAP lesions (16%).

Surgical patients were classified into one of three groups based on the operative procedure. Open capsulorrhaphy (OC) included twenty subjects (15 men, 5 women) who underwent an open capsular placation; 14 of these underwent concurrent Bankart repair. Arthroscopic thermal capsulorrhaphy (TC) included 16 subjects (8 men, 8 women) who underwent arthroscopic thermal capsulorrhaphy, 7 of whom had a concurrent Bankart repair. Arthroscopic capsulorrhaphy (AC) involved 9 subjects (6 men, 3 women) who underwent arthroscopic capsular plication, 8 of whom had a concurrent Bankart repair. Control group subjects were sex and age-matched across surgical groups to minimize the confounding effects of age on proprioception.[26] Demographic data for the surgical and control groups are summarized in Table I.

Surgical patients were tested retrospectively at an average of 33.4 ± 21.0 months after surgery. Subjects provided informed consent prior to participation, as approved by our Institutional Review Board for the Protection of Human Subjects.

Joint position sense protocol

We assessed glenohumeral joint position sense (JPS) by employing a passive reproduction of passive positioning protocol with an isokinetic dynamometer (Biodex System 3 Pro™; Biodex Medical, Inc., Shirley, NY). A custom-designed shoulder-positioning device secured the subject's limb to the dynamometer (Figure 1). Prior to testing maximum passive external rotation (ER_{max}), range of motion was measured bilaterally using the dynamometer's internal goniometer, while the subject was in a seated position with the shoulder abducted to 90° in neutral rotation. Two relative target angles were then calculated to evaluate JPS for each subject, based on 60% (mid-range) and 90% (end-range) of the ER_{max} value for each shoulder. This JPS testing paradigm has been used to calculate target angles in 2 previous studies.[19,38]

To familiarize the subjects with the JPS protocol, a single practice trial at each target angle was performed on each limb. Each subject was blindfolded, while seated on the dynamometer chair, with his or her shoulder in a position of function in the frontal plane (90° of shoulder abduction and elbow flexion, in neutral rotation) (Figure 1). To minimize sensory input from cutaneous receptors, a 13 cm wide stockinette was placed over the subject's arm from the fingers to the mid-brachium, and an upper-extremity vacuum splint (Cramer Products, Inc., Gardner, KS) was applied and inflated evenly over the stockinette. The splinted limb was then secured to the dynamometer's lever arm with a 15 cm elastic bandage. After a standardized warm-up of 1 practice trial at each target angle to acquaint the subject with the experimental setup, the continuous passive motion (CPM) mode of the dynamometer was activated for JPS testing.

The shoulder under investigation was passively rotated by the dynamometer at 10°/s from neutral rotation to 1 of the 2 target positions, 60% ER_{max} or 90% ER_{max}. The order of JPS testing was counterbalanced between limbs and between target positions to control for learning bias and testing fatigue. The target position was maintained for 10 seconds, with subjects verbally instructed to focus on the position of the shoulder. The arm was passively returned to the starting position at 30°/s and rested for 5 seconds. The dynamometer then passively moved the shoulder into external rotation at 10°/s. Subjects were instructed to identify the target position by pressing a hand-held cutoff switch to stop the dynamometer when they perceived that the target angle had been reached. A total of 6 trials was performed on each shoulder, eg, 3 trials at the 60% ER_{max} position and 3 trials at the 90% ER_{max} position.

The dynamometer's software permitted measurement of the reproduction of the target position to the nearest whole

Table I Demographics for surgical groups and control subjects

	Group demographics				
	Open	**Arthroscopy**	**Thermal**	**Control**	**Total/mean**
Total No. shoulders	20	9	16	22	N = 67
Age (mean ± SD)	28.0 ± 9.6	20.2 ± 1.2	21.0 ± 2.1	23.8 ± 5.7	23.3 ± 4.6
Males:Females	15:5	6:3	7:9	11:11	39:28
Months post surgery	41.84 ± 29.9	26.5 ± 19.9	27.5 ± 15.7	——	33.4 ± 24.0
Surgical limb passive external rotation ROM at 90° abduction	80.1 ± 3.2°	93.1 ± 4.8°	93.3 ± 2.3°	——	88.8 ± 3.4°
Mean loss of external rotation in surgical limb (compared to opposite limb)	11.9°	4.9°	3.8°	——	6.8°

Figure 1 Experimental setup for measurement of joint position sense with a Biodex MultiJoint System 3 isokinetic dynamometer.

degree. Joint position sense accuracy was calculated as the absolute value of the difference (in degrees) between the target and the joint position identified by the subject. The results of the 3 trials at each position were averaged to represent the absolute target error for each of the JPS tasks.

Experimental design and statistical analysis

A group (4) x target angle (2) mixed design ANOVA was conducted to examine the effects of experimental group (control, OC, AC, TC) and target angle (60% ER_{max} and 90% ER_{max}) on joint position sense. Additionally, a surgical group (3) x limb (involved/uninvolved limb) blocked ANOVA was performed on the joint position sense data. Statistical significance was set *a priori* at $\alpha = 0.05$, and when main effects were observed, we employed Scheffé post hoc analysis to identify simple main effects ($P = .05$). Data from one OC subject were identified as an outlier, ie, greater than 3.3 standard deviations from the group mean and removed from the analysis.[39]

RESULTS

Significant differences in mean target error ($F_{(3,65)}$=4.37, $P < .01$, $\eta^2 = .18$) were observed among groups at the mid-range position (60% ER_{max}) of shoulder external rotation (Figure 2). Posthoc analysis revealed that open capsulorrhaphy and thermal capsulorrhaphy patients each demonstrated significantly less target error (5.4° ± 3.3° and 5.6° ± 3.3°, respectively) than arthroscopic patients (9.2° ± 3.7°) at the mid-range position (Scheffé $P < .01$ and $P < .05$, respectively). Interestingly, the control subjects' dominant shoulders had significantly less JPS accuracy (8.1° ± 4.0°) than the repaired shoulders of open capsulorrhaphy (5.4° ± 3.3°; Scheffe' $P < .01$) and thermal capsulorrhaphy patients (5.6° ± 2.4°; Scheffe' $P < .05$) at mid-range (Figure 2). Across surgical groups, we observed no significant differences in joint position sense between the repaired shoulders and the contralateral normal shoulders at either the mid-range or end-range (90% ER_{max}) of external rotation ($P > .05$, 1-β= 0.1) (Table II).

Target reproduction error was significantly less across experimental groups at the 90% ER_{max} target position (4.5°± 2.5°) than at the 60% ER_{max} position (6.7°± 3.5°) ($P < .001$). In general, there was a trend toward undershooting the target position as 66% of subject trials undershot the target.

DISCUSSION

The results of this study indicate that joint position sense accuracy in repaired shoulders was similar to the contralateral normal limb regardless of operative technique. Our findings support the hypothesis that surgical retensioning of the anterior glenohumeral capsule and muscles restores the somatosensory aspects of the joint that contribute to joint stability. Furthermore, the repaired shoulders of the open capsulorrhaphy and thermal capsulorrhaphy patients demonstrated better position sense at midrange, and equal position sense at end-range, than the arthoscopic capsulorrhaphy patients and the normal shoulders of age-matched controls. These findings are consistent with previous reports on joint position sense in surgically-repaired shoulders,[2,23,33] but represent the first direct comparison of thermal capsulorrhaphy patients with open and arthroscopic capsulorrhaphy patients.

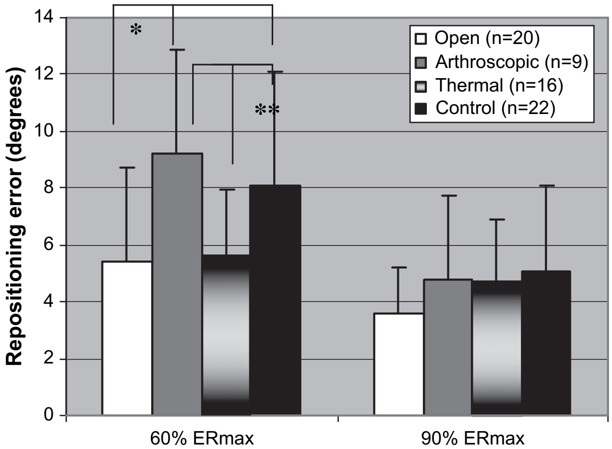

Figure 2 Joint position sense absolute error (mean ± SD) at 60% and 90% of passive ER_{max}. Open capsulorrhaphy group had significantly less absolute error than the arthroscopic and control groups ($P \leq .01$). Thermal capsulorrhaphy group significantly less absolute error than the arthroscopic and control groups ($P < .05$).

In a retrospective study such as ours, the optimal type of capsular reconstruction for re-establishing proprioception cannot be conclusively determined, because no baseline JPS data exist for our subjects. A recent prospective study by Potzl et al[33] provides the best current evidence of restored proprioception. These authors reported preoperative bilateral JPS deficits in patients with anterior shoulder instability and observed significant bilateral improvement in JPS following open and arthroscopic surgical repair at an average of 5.9 years follow-up.

Previous retrospective studies by Lephart et al[22,23] have suggested that a normalization of shoulder JPS occurs following traditional open and arthroscopic capsulorrhaphy,[23] as well as after thermal capsulorrhaphy.[22] These authors compared the repaired and uninvolved limbs of postsurgical patients and found no significant differences between limbs; however, they also did not obtain preoperative JPS measurements. Lephart et al[22] observed reproduction of passive positioning (RPP) error values ranging from 1.6° to 2.7° in the repaired shoulders of thermal capsulorrhaphy patients and, in an earlier study, observed RPP error values of 2.0° to 3.5° in open and arthroscopic capsulorrhaphy patients.[23] These error values are lower than those observed in our patient sample, which is likely due to differences in patient positioning during testing protocols.

Both our experimental methodology and Lephart's provide an indirect measurement of the proprioceptive status in surgically-repaired shoulders. Our protocol, however, was able to shed light on the extent to which JPS accuracy differed among thermal, open, and arthroscopic surgical techniques. Our open and thermal capsulorrhaphy patients demonstrated significantly better JPS accuracy than arthroscopic patients and control subjects, averaging between 31% to 41% less repositioning error.

Considering the open capsulorrhaphy patients, 2 likely mechanisms may explain their heightened joint position sense. First, the results of three previous studies support the belief that more optimal glenohumeral capsular retensioning is accomplished with open techniques than with arthroscopy.[25,32,35] Because mechanoreceptors embedded in the joint capsule are stimulated in proportion to the capsular tension achieved during passive joint rotation,[13] it appears that the re-tensioning accomplished with open capsulorrhaphy effectively facilitated afferent feedback in the repaired joint capsule.

Second, joint position sense may have been heightened through enhanced information provided by musculotendinous receptors during JPS testing.[26] Because the subscapularis was surgically manipulated through horizontal division (70% of the subjects) and through lateral detachment and advancement (30% of the subjects) in our open arthrotomy group, this may have resulted in increased scarring and shortening of the muscle. As a result, muscular tension was likely increased within the subscapularis and other incised anterior shoulder musculature during JPS testing into passive external rotation. The eccentric resistance to elongation in these antagonists, eg, subscapularis, pectoralis major, and latissimus dorsi, likely activated Golgi tendon and muscle-spindle afferents, enhancing joint position sense.[26,29]

Whether or not the increased joint capsule and muscular tension after open capsulorrhaphy is a desirable outcome is of interest. Indeed, these factors may have created an inelastic joint with heightened sensitization to external rotation movement, as a result of loss of external rotation motion. We observed an external rotation ROM deficit of 11.9° in the open capsulorrhaphy patients (Table I). Such a deficit would seem to suggest an undesirable outcome; however, we observed a poor correlation ($R = -.09$, $P = .55$) between patients' available postoperative ROM and their satisfaction with surgery. Therefore, postoperative external rotation motion did not significantly influence patient perception of their postsurgical status.

In contrast, the relationship between ROM and JPS was significant ($R = .46$, $P > .05$) at mid-range of external rotation (60% ER_{max}), but was not significant ($R = .15$, $P = .31$) at end-range of rotation (90%ER_{max}). This suggests that patients with decreased ROM had heightened JPS in mid-range of rotation as a function of their limitation, while patients with more available ROM had increased JPS error. Taken together, these findings suggest that heightened JPS was a function of available ROM but was not necessarily an undesirable outcome, as it was not negatively correlated with patient satisfaction.

Table II Joint position sense accuracy in repaired versus normal limbs at mid-range and end-range of external rotation.

Group	60% ERmax (°)*Mean* ± *SD*			90% ERmax (°)*Mean* ± *SD*		
	Repaired limb*	Normal limb	*P* value	Repaired limb*	Normal limb	*P* value
Open	5.4 ± 3.3	6.6 ± 3.9	0.13	3.5 ± 1.7	3.6 ± 1.9	0.87
Arthroscopic	9.2 ± 3.7	8.3 ± 5.3	0.89	4.2 ± 1.3	4.9 ± 1.2	0.48
Thermal	5.6 ± 2.4	6.4 ± 2.9	0.33	4.7 ± 2.5	5.1 ± 2.7	0.60

*No significant differences existed between the repaired shoulders and the contralateral normal shoulders across surgical groups ($P > 0.05$).

It was surprising that thermal capsulorrhaphy patients demonstrated significantly better JPS than arthroscopic capsulorrhaphy patients. Given the collagen denaturation known to occur with thermal repair,[15-17,37,41] we hypothesized that the mechanoreceptors located in the joint capsule would be damaged in similar fashion. However, thermal repair did not appear to affect shoulder proprioception negatively in our sample of patients. Our results extend the findings of Lephart et al,[22] who observed comparable proprioception in the repaired and contralateral shoulders at 12 months after thermal repair. We observed bilateral symmetry at an average of 27.5 months follow-up. Furthermore, the thermal patients demonstrated better involved-limb proprioception than uninjured shoulders of age and sex-matched controls.

The exact mechanism by which joint position sense was heightened in thermal capsulorrhaphy patients is unclear; primarily because we could find no histologic studies indicating whether mechanoreceptors embedded in the joint capsule are ablated during surgery or whether subsequent neural reinnervation occurs during tissue remodeling. Yet, insight from other literature evaluating the neural properties of altered human graft tissue may be helpful.[1,34] Studies in the knee have demonstrated repopulation of mechanoreceptors in ACL-autografts following ACL-reconstruction.[1,34] Histologic examination after thermal capsulorrhaphy is clearly needed to clarify the effects of thermal capsulorrhaphy on joint mechanoreceptors.

Finally, we observed greater joint repositioning accuracy at the end-range of glenohumeral external rotation than at mid-range. This finding agrees with Janwantanakul,[19] who also reported more accurate joint position sense at the end-range of external rotation than at the midrange position. Our 90% ER_{max} testing position in the plane of the scapula was likely more effective than the 60% ER_{max} target position at activating specific mechanoreceptors, eg, Ruffini endings, that detect end-range of joint motion.[13] Ruffini endings play little or no role in detecting midrange joint positions.[11-13] Because we took into account each individual's joint mobility when setting target positions during proprioception testing, we were able to ensure that each subject was tested at the same proportion of their maximal tissue tension at end range of rotation.

We recognize that the limitations of our retrospective study design include no standardized period of rehabilitation for surgical patients and nonrandom assignment of patients to surgical groups, potentially resulting in selection bias. Also, the decision to perform open, arthroscopic, or thermal stabilization was based on surgeon preference, after considering the specific shoulder pathology during examination. Finally, the small sample of arthroscopic capsulorrhaphy patients warrants additional investigation with a larger patient sample.

CONCLUSIONS

Joint position sense for external rotation movements was similar between the postsurgical and contralateral normal shoulders in thermal, open, and arthroscopic capsulorrhaphy patients treated for recurrent, anterior glenohumeral instability. Open and thermal capsulorrhaphy patients demonstrated better repaired-limb joint position sense than arthroscopic patients and control subjects dominant limbs. The exact mechanisms responsible for these differences should be studied further, including histologic examination after thermal capsulorrhaphy. Controlled studies are still needed to compare the long-term benefits and complications of these stabilization procedures.

The authors thank David Chao, MD, James Collins, ATC, and Aaron Miller, ATC, for their assistance. We also thank the National Athletic Trainers' Association and the Northwest Health Foundation for funding this research.

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