AN ABSTRACT OF THE DISSERTATION OF

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PURPOSE: To compare glenohumeral joint position sense (JPS), concentric internal (IR) and external rotation (ER) strength, functional ability, and level of satisfaction in patients who underwent three types of glenohumeral capsulorrhaphy with age-matched controls. RESEARCH DESIGN: Four 4 x 2 and two 4 x 3 ANOVAs were used to identify differences in JPS and concentric IR/ER strength between groups: Open Capsulorrhaphy (n = 21), Thermal Capsulorrhaphy (n = 16), Arthroscopic Capsulorrhaphy (n = 14) and Controls (n = 22). Pearson correlation analyses were performed to determine the relationship between objective American Shoulder and Elbow Surgeons (ASES) evaluations and subjective Shoulder Rating Questionnaire (SRQ) scores. Stepwise multiple regression analyses were performed to predict ASES and SRQ scores from various objective and subjective outcome measures. SUBJECTS: 73 adults (51 postsurgical patients, 22 healthy controls; mean age, 23.7 ± 6.8 yrs) participated in this retrospective study. The 51 patients who underwent capsulorrhaphy for recurrent, anterior glenohumeral instability were evaluated at an average of 32.1 months postsurgery. MEASUREMENTS: JPS was measured bilaterally using a reproduction of passive positioning protocol at 2 target angles: 60% and 90% of maximum passive external rotation (60% and 90% ER_{max}). Concentric IR and ER peak torques were measured bilaterally at 90°/sec, 180°/sec and 270°/sec. Objective postoperative function was quantified with the clinician-based ASES form, while functional status and patient satisfaction were assessed with the patient-based SRQ form. RESULTS: The accuracy of JPS in patients' surgical limbs was similar to that present in their contralateral, uninjured shoulders at both target angles. The Open group demonstrated significantly better involved-limb JPS acuity (4.2° ± 1.9°) than the Arthroscopic group (6.8° ± 3.2°) and Control group (6.6° ± 3.5°) ($p < .05$). However, the Open group had 31% less IR strength than Control subjects and 33% less than the Arthroscopic group, with IR peak torques significantly less in their postsurgical shoulders than their uninvolved limbs ($p < .002$). There was a strong, positive correlation ($r = .64$, $p \leq .001$) between objective ASES and subjective SRQ scores. Patients' postoperative level of pain and ASES scores were significant predictors of their SRQ clinical scores ($R = .81$, $p < .003$). CONCLUSIONS: Glenohumeral JPS and rotator cuff strength were similar in both the postsurgical and uninvolved shoulders of the Arthroscopic and Thermal groups. Patients in the Open capsulorrhaphy group demonstrated significantly better involved-limb JPS than Arthroscopic and Control groups. The large strength deficits observed in the Open group, particularly in IR, were of significant concern. We observed a higher failure rate, more revision surgeries, and lower patient satisfaction with the Thermal capsulorrhaphy technique. Patient-based outcomes were significant predictors of operative success as measured by clinician-based evaluation. Prospective, randomized controlled studies are still needed to evaluate the outcomes of these glenohumeral capsulorrhaphy procedures over the longer term.

Evaluation of Outcomes following Thermal, Open and Arthroscopic Glenohumeral Capsulorrhaphy for Recurrent Anterior Instability

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Jeff A. Sullivan, Author

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This manuscript is dedicated to the most important people in my life, who deserve acknowledgment. To my wife, Hannah, your patience throughout this long process has amazed me. Our lives would have been easier without this; thank you for letting me chase after my goal. I'm finally done, I promise! To daddy's girl, Makenna: Yes, I can dance with you now! To my son, Jacob, born 2 weeks before the defense of this manuscript, you already make your dad proud! I love each of you.

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CHAPTER 1

INTRODUCTION

Glenohumeral joint instability presents a significant clinical challenge to sports medicine practitioners. The glenohumeral joint is the most frequently dislocated major joint in the body, with 80-95% of traumatic cases occurring anteriorly.[74] Anterior instability is particularly difficult to resolve in the young, active patient with a first-time dislocation, but is also problematic for athletes participating in high-contact or collision sports.[2, 52, 62] The frequency of recurrent instability in these patients has been reported as high as 80-94%.[23, 38, 62] Whether caused by congenital laxity, acute trauma, or repetitive microtrauma, the natural history of anterior instability frequently includes recurrent episodes of subluxation that further diminish joint stability and function.[54, 62] These recurrent incidences of shoulder instability may prevent patients from returning to their previous activity levels and may initiate the onset of premature osteoarthritis.[62]

Glenohumeral joint instability can range in severity from a vague sense of dysfunction, i.e., atraumatic or subtle instability, to a traumatic episode of gross dislocation.[36] Four criteria are generally used to classify instability and to guide treatment: (a) *degree*, i.e., subluxation or dislocation; (b) *frequency*, i.e., acute or chronic/recurrent; (c) *origin*, i.e., traumatic, atraumatic, or acquired; and d) *direction*, i.e., unidirectional, bidirectional, or multidirectional.[3, 4]

The stability of the glenohumeral joint is dependent on the complex synergy of ligamentous integrity, muscular stability, and osseous congruity of the joint.[25, 43, 44, 48] Static stabilizers, including the ball and socket joint configuration, capsuloligamentous structures, and the glenoid labrum, guide arthrokinematics by providing mechanical restraints to external stresses.[12, 48, 49] Dynamic stability is provided by the rotator cuff, the biceps long head, and the scapular and humeral movers.[15, 22, 25, 57, 74] The rotator cuff is ideally positioned to compress the humeral head into the glenoid fossa throughout the full glenohumeral arc of motion[16 4, 15, 16, 18] Often referred to as the "compressor cuff", it exerts an inferomedial vector of pull on the humeral head to center it in the glenoid fossa. In particular, the subscapularis, infraspinatus, and teres minor partner in glenohumeral force couples to oppose the superior vector of pull of the anterior deltoid, thus preventing glenohumeral impingement.[27, 64, 73, 74]

The primary pathology associated with traumatic, anterior dislocation involves mechanical detachment of the anteroinferior labrum, with its attached inferior glenohumeral ligament complex, from the glenoid rim and scapular neck.[33] Known as the classic Bankart lesion, this pathology has been described as the "essential lesion" that underlies recurrent episodes of instability.[27, 41, 47] A combination of compromised mechanical restraints and the ensuing impairment in neuromuscular stabilization of the joint likely contributes to the progressive decline in shoulder function common among patients with anterior instability.[15, 44, 45, 54]

Surgical Management of Glenohumeral Instability

Unfortunately, glenohumeral instability remains difficult to resolve surgically. One current perspective is that surgical management works best in the young patient with a history of traumatic, unidirectional dislocation to eliminate or minimize the risk of recurrence.[62] Conversely, the patient with atraumatic, multidirectional instability is commonly advised to try conservative management prior to surgical repair.[11, 62] However, the efficacy of conservative management of first-time dislocations has recently been challenged as it does not significantly reduce the rate of recurrent instability.[62, 22, 72] Consequently, numerous open and arthroscopic surgical approaches have been advocated to address the pathophysiology associated with anterior instability.[62]

Open Capsulorrhaphy (OC). The open Bankart surgical procedure is designed to re-establish the original glenohumeral anatomy, and has long been the surgical gold standard for managing anterior instability based on high success rates limiting recurrent episodes of instability to 1 to 10%.[3, 4, 11, 23, 31, 36, 49, 52, 55, 60, 61] In the open repair, redundant capsular tissue is treated with capsulorrhaphy, which involves dividing and shifting the capsule using either a suture punch or hook to advance and secure the capsule.[16, 42, 60] To repair the Bankart lesion, a bony tunnel is created through the anteroinferior glenoid fossa to the glenoid neck. Suture strands are passed through the edge of the capsule and labrum to advance these structures to their normal anatomic position on the anteroinferior glenoid. Particular care is taken to retension the inferior and middle glenohumeral ligaments relative to the glenoid rim and neck.[40] This procedure successfully reconstructs the normal length, tension and relationship of the capsuloligamentous structures that are commonly affected by traumatic instability.[40, 60, 61]

Candidates for open repair generally include patients with excessive anterior laxity and ligamentous fraying; patients with an osseous lesion, e.g., Hill-Sachs or bony Bankart lesion; and contact and collision sport athletes.[3, 4, 11, 52] However, since its introduction, a frequent complication of the open repair has been over-constraint of the capsule and excessive scarring of anterior musculature.[40, 55, 58, 60] These complications, attributed to anatomic resection of anterior structures in order to visualize the joint, often result in limited range of motion and decreased ability to return to overhead sport activities,[16, 17, 40, 55]

Arthroscopic Capsulorrhaphy (AC). Arthroscopic surgical techniques to eliminate glenohumeral instability have become increasingly popular as they potentially lead to more accurate identification of intra-articular pathology, less postoperative pain, fewer surgical complications, and greater returns in postoperative range of motion.[3, 4, 8, 11, 18, 24, 47, 52] Arthroscopic repair is indicated for high performance, overhead sports athletes with traumatic, unidirectional instability desiring full postoperative motion.[3, 4, 8, 11] These patients likely have an isolated Bankart lesion without significant capsular laxity or substantial internal derangement of the joint.[4, 11]

Of concern were higher initial failure rates experienced with arthroscopic repair, ranging from 5% to 60%[2, 11, 24, 47] as compared with open approaches, ranging from 1% to 10%.[3, 4, 11, 23, 31, 36, 49, 52, 55, 60, 61] The initial arthroscopic procedures at the shoulder involved suture capsulorrhaphy—a single-point fixation of the Bankart lesion to the glenoid.[3, 8] Also, transglenoid sutures have been used to anchor the labrum, spanning the scapular neck.[24, 51] These techniques resulted in an array of complications and failure rates as high as 50%.[4, 11, 24] They have subsequently been replaced by newer techniques using bioabsorbable implants and suture anchors.[11] These techniques mimic open Bankart repair by anchoring a Bankart lesion to the glenoid, and using suture plication to restore normal tension to the capsuloligamentous structures.[11] Current outcomes with these suture-plication techniques are comparable, and may be equivalent, to open repair.[2, 4, 11] A limited number of follow-up studies have evaluated the outcomes in these newer arthroscopic techniques versus open stabilization.[2, 4, 11]

Thermal Capsulorrhaphy (TC). Recently, thermal energy has been introduced in arthroscopic procedures to decrease shoulder instability due to capsuloligamentous redundancy.[4,65,66] Thermal capsulorrhaphy (TC) procedures utilize either laser or radiofrequency energy to heat shoulder capsular tissue, causing significant collagen shrinkage and reducing capsular volume.[21,46,50,63] Thermal capsulorrhaphy has been increasingly recommended for overhead athletes with acquired instability who require full postoperative range of motion to return to activity.[9,73] Theoretically, thermal capsulorrhaphy is best suited for treating excessive capsular volume, as seen in patients with anteroinferior and multidirectional instability. When concomitant pathology exists, e.g., a Bankart or SLAP lesion, thermal capsulorrhaphy is typically performed in combination with arthroscopic labral repair.[1,68]

Preliminary thermal capsulorrhaphy clinical studies yielded encouraging results in stabilizing the shoulder, and allowed patients to return to both competitive athletics and military duties.[9,10] However, the process of thermal capsular shrinkage involves significant collagen denaturation, which has been shown to cause deleterious effects on the histological, and biomechanical properties of collagen tissue.[21,46,50,63] Wall et al.[70] demonstrated that collagen shrinkage of greater than 20% resulted in increased tissue extensibility, causing specimens to stretch beyond their original length under stress. In contrast, Hecht et al.[21] noted that while radiofrequency energy altered the stiffness of capsular tissue in an ovine model, the treated tissue began to approach normal stiffness at 6 to 12 weeks after surgery. Using electron microscopy, Hecht and colleagues observed normal collagen appearance 12 weeks after surgery. Thus, it appears that thermal energy initially damages collagen tissue; however, the long-term effects of altered collagen tissue on functional outcomes remain to be determined.

While the potential of thermal capsulorrhaphy has been evolving, the orthopedic community generally considers it to be an experimental procedure.[5, 32, 47] Despite its investigational status, the implementation of thermal repair by orthopedic surgeons has outpaced controlled trials evaluating its efficacy. Current clinical results are disconcerting. Significant postoperative complications such as osteonecrosis and chondrolysis have been demonstrated.[10, 13, 53] In addition, failure rates as high as 50% have been observed after thermal capsulorrhaphy in patients with multiple directions of instability.[5] As a result, many surgeons now incorporate thermal capsulorrhaphy sparingly, as an adjunct to Bankart repair for addressing capsular laxity.[5, 10, 53] Clinical trials are overdue examining the long-term effects of thermal energy applied to *in vivo* human glenohumeral collagenous structures.

Assessment of Surgical Outcomes

Proprioception. While advances in surgical stabilization have successfully restored static stability to the glenohumeral joint, less progress has been made in understanding the complex contributions of proprioception and neuromuscular control to dynamic shoulder stability. Proprioceptive mechanisms appear to mediate functional joint stability by facilitating the alliance between static and dynamic stabilizers.[25, 43, 48]

Histological studies have confirmed the presence of proprioceptive mechanoreceptors in the glenohumeral joint capsule and ligaments.[15, 69] Many authors[29, 30, 44, 54, 67] have hypothesized that a neurofeedback loop exists between these afferent receptors and glenohumeral muscular stabilizers, and that traumatic or atraumatic disruption of this loop inhibits normal reflexive joint stability.[43] Using a feline model, Gaunche et al.[14] demonstrated the existence of a reflex arc from the glenohumeral joint capsule to several muscles crossing the joint. Tibone et al.[67] later confirmed the existence of this reflex mechanism in human shoulders. These authors monitored somatosensory cortical evoked potentials through scalp electrodes to provide direct evidence of an afferent pathway originating in the glenohumeral joint capsuloligamentous structures and terminating in the cerebral cortex. Interestingly, the authors did not find significant differences in the reflex arc between healthy subjects and those with unstable shoulders.

In contrast, Lephart et al.[30] demonstrated impaired proprioception in patients with unstable shoulders when compared with their contralateral uninjured limbs. Tibone and colleagues[67] suggested that these findings were either the result of gross injury to neural elements within the reflex pathway, or that these elements were simply not being activated properly. Freeman and Wyke[12] originally proposed this process of partial "deafferentation" in which injury to articular structures results in a disruption of normal joint mechanoreception and inhibits reflexive neuromuscular control of the joint.

Several authors have documented that surgical methods aimed at restoring normal glenohumeral capsular tensioning may combat the problem of functional instability by preserving mechanoreceptors.[25, 26, 30, 54] However, the best type of glenohumeral capsular reconstruction for preserving proprioceptive structures remains unknown.[54] Of particular interest is objective assessment of the effect(s) that thermal energy has on glenohumeral joint mechanoreceptors. Articular mechanoreceptors may be damaged in similar fashion to the collagen tissue that is denatured.[21, 46, 50, 63] Conversely, neural reinnervation may occur in collagen structures concomitantly with the return of normal biomechanical properties after thermal exposure. No published evidence is currently available to support or refute this notion. While one prospective study has examined shoulder proprioception before and after arthroscopic and open capsulorrhaphy,[56] no single study has compared the postoperative outcomes of patients treated with all three surgical techniques: open, arthroscopic and thermal capsulorrhaphy.

Potzl et al.[56] found preoperative deficits in joint position sense in involved shoulders versus healthy controls, but involved shoulders became significantly more accurate than controls postoperatively. In addition, comparable proprioception has been demonstrated in repaired versus uninvolved shoulders after thermal repair,[28] at an average of 12 months postoperatively. However, the long-term effects of thermal collagen denaturation on glenohumeral articular proprioceptors remain to be determined.[68]

Glenohumeral Joint Strength. Changes in glenohumeral joint rotator cuff strength relationships are viewed as one of the causes of shoulder dysfunction.[6] Rotator cuff strength, as measured by peak torque, and agonist/antagonist balance, quantified via external rotation/internal rotation peak torque ratio, appear to be predictive of dynamic joint stability since the static stabilizers of the joint do not effectively provide stability until end range of motion.[37]

Most research evaluating rotator cuff strength has involved healthy participants, or those with instability and impingement,[71] with few studies examining strength in postsurgical patients.[7, 19, 20] Ellenbecker and Matallino[7] observed comparable rotator cuff strength in involved versus uninvolved shoulders at 12 weeks after thermal capsulorrhaphy. Hartsell[20] demonstrated similar results at 32 months in patients treated with Bankart-type anterior stabilization. We have found no published studies that have directly compared peak torque and external rotation/internal rotation strength ratios in patients treated with open, arthroscopic and thermal capsulorrhaphy.

Subjective Outcomes: A Patient-Based Perspective. Determining the optimal treatment for instability requires a multifaceted decision-making process. Factors influencing the selection of treatment include the classification of instability, the particular sport/activity to which the patient desires to return, the patient's postoperative goals, and the level of experience of the surgeon in performing the stabilization technique.[11, 24, 34, 35, 39, 52]

The ultimate decision regarding treatment lies with the patient and depends on their perceptions following the surgeon's evaluation and advice.[35] Yet the evaluation of patient-based outcomes, including satisfaction and postoperative functional ability, is frequently missing from published clinical studies. Mancuso et al.[35] identified the following surgical expectations as most frequently cited by patients with instability prior to surgery: "ability to return to sports", to "stop dislocation", and to have their "shoulder back to the way it was before injury". While a variety of shoulder scoring systems are currently utilized to assess these objective and subjective clinical results, a universally-accepted evaluation instrument has not been adopted. This is likely due to limited psychometric data evaluating validity, correlation, and interrater reliability among these systems.[59] Further, contemporary shoulder scoring systems are not highly correlated. Romeo et al.[59] evaluated the comparability of four commonly used shoulder scoring systems. These authors measured outcomes in patients after open and arthroscopic

Bankart stabilization, observing significant variations in the scores of these systems while evaluating identical shoulder outcomes with each.

It is necessary to evaluate individual objective and subjective outcomes of shoulder strength, proprioception, functional ability, and satisfaction in surgically-repaired and contralateral uninvolved shoulders. Also, the extent to which these clinical outcomes are interrelated remains to be determined in patients treated for anterior instability.

PURPOSE OF THE STUDY

The optimal technique for the surgical management of recurrent anterior glenohumeral instability has not yet been identified. Long-term outcomes using newer arthroscopic procedures are needed to determine their effectiveness versus open repair in diminishing recurrent instability. We could find no published studies that have directly compared proprioception, strength, and functional outcomes after open, arthroscopic, and thermal capsulorrhaphy. The purpose of this research was to compare glenohumeral joint position sense, isokinetic internal and external rotation strength, functional ability, and level of satisfaction in patients who underwent these common capsulorrhaphy procedures, and compare them to healthy, age-matched controls. Our hypotheses were that the postoperative outcomes of patients in the three surgical groups would not differ significantly, and that objective measures of patients' shoulder function would correlate highly with postoperative level of satisfaction.

The results of this investigation are summarized and presented in the proceeding chapters. The first manuscript (Chapter 2), entitled "Shoulder proprioception, strength, and patient satisfaction following thermal, open, and arthroscopic capsulorrhaphy for recurrent instability" will be submitted for publication in the **American Journal of Sports Medicine**. The results of this study are scheduled to be presented at the National Athletic Trainers' Association Annual Meeting in Indianapolis in June 2005. The abstract of this paper has been recognized as a finalist for the NATA Research and Education Foundation's "Outstanding Doctoral Research Award", to be determined following the oral presentation of the results at the upcoming NATA meeting.

The second manuscript (Chapter 3), entitled "Patient-based outcomes predict operative success in the treatment of glenohumeral instability: A comparison of open, arthroscopic, and thermal capsulorrhaphy techniques", will be submitted for publication in the American volume of the **Journal of Bone and Joint Surgery**. An abstract of this study will be submitted for presentation at the 2006 American College of Sports Medicine Annual Meeting.

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CHAPTER 2

Shoulder proprioception, strength, and patient satisfaction following thermal, open, and arthroscopic capsulorrhaphy for recurrent anterior instability

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Abstract

Background: No previous studies have made direct comparisons of the outcomes of thermal, open and arthroscopic surgical procedures designed to eliminate recurrent anterior glenohumeral instability. As a result, the optimal surgical procedure to correct anterior glenohumeral instability has not yet been conclusively identified.

Hypotheses: Glenohumeral joint position sense, muscular strength, functional ability, and overall patient satisfaction will be comparable among the three surgical procedures, and between surgically-repaired and age-matched control group shoulders. Patients' subjective assessments of their postoperative outcomes will be positively correlated with their objective clinical findings.

Study Design: Retrospective, cross-sectional, 4 x 2 ANOVA case-control study; Level of evidence, 3.

Methods: 73 adults (51 postsurgical patients, 22 healthy controls) participated in this study. Surgical subjects were referred to the study by their surgeon after thermal, open or arthroscopic capsulorrhaphy to repair recurrent, anterior shoulder instability. The involved and contralateral normal shoulders of all surgical subjects were tested at an average of 32.1 ± 24.8 months postsurgery (range, 6 to 96 months). Measures of joint position sense (JPS), quantified as the ability to reproduce passive positions of 60% and 90% of maximum passive external rotation (ER_{max}) were obtained for each subject. Concentric internal (IR) and external rotation (ER) peak torque values and agonist/antagonist ratios (ER/IR) were evaluated at 90°/sec, 180°/sec and 270°/sec with an isokinetic dynamometer. Objective postoperative function was quantified with the

American Shoulder and Elbow Surgeons' shoulder evaluation form (ASES), while functional status and patient satisfaction were assessed with the Shoulder Rating Questionnaire (SRQ).

Results: The accuracy of JPS in patients' surgical limbs in all three groups was similar to that present in their contralateral, uninjured shoulders at both the mid-range (60% ER_{max}) and end-range (90% ER_{max}) target positions. The Open group demonstrated significantly better involved-limb JPS acuity (4.2° ± 1.9°) than the Arthroscopic group (6.8° ± 3.2°) and the Control group nondominant limbs (6.6.° ± 3.5°). No significant differences in JPS were observed between the Thermal group patients (5.2° ± 2.3°) and the Arthroscopic or Open groups. All groups had more accurate JPS near the end-range of ER (4.5° ± 2.5°) than at mid-range (6.7° ± 3.5°) ($P < 0.001$). The Open group had 31% less IR strength than the Control group ($P = .007$), and 33% less than the Arthroscopic group ($P = .013$), with IR peak torques significantly less in their postsurgical shoulders compared to their uninvolved limbs ($P = .002$). The shoulders of the Thermal group patients generated significantly less IR peak torque at 90°/sec ($P \leq .013$) than the Arthroscopic group. The ER/IR peak torque ratios were not significantly different among the surgical groups ($P > 0.05$, $1 - \beta = .73$). We observed a strong, positive correlation ($r = .64$, $P \leq .001$) between objective ASES and subjective SRQ scores.

Conclusions/Clinical Relevance: Joint position sense and rotator cuff strength were similar in both the postsurgical and uninvolved shoulders of the Arthroscopic and Thermal groups. Patients in the Open capsulorrhaphy group demonstrated significantly better involved-limb JPS than the Arthroscopic and Control groups. The large strength deficits observed in the Open group, particularly in internal rotation, were of significant concern. Open capsulorrhaphy patients demonstrated the greatest loss of active external rotation range of motion in their surgical limbs (13.4°) at 90° of glenohumeral abduction compared with Arthroscopic (4.5°) and Thermal (2.2°) capsulorrhaphy patients. While this study was the first to make direct comparisons among thermal, open and arthroscopic capsulorrhaphy; randomized, prospective clinical studies are still needed to evaluate the long-term results of these procedures in the treatment of recurrent anterior glenohumeral instability.

Keywords: glenohumeral joint; anterior instability; thermal capsulorrhaphy; arthroscopic Bankart; open capsulorrhaphy.

The optimal treatment of anterior glenohumeral instability (AGHI) remains a contentious and challenging issue, with surgical repair having limited success, particularly in young athletes.[36, 73] Whether caused by congenital laxity, acute trauma, or repetitive microtrauma, the natural history of AGHI includes recurrent episodes of instability.[48, 50, 73] Detachment of capsulolabral structures from the anteroinferior glenoid rim (a "Bankart lesion"), and/or capsular attenuation comprise the majority of cases of AGHI.[50, 56, 64]

Surgical management of AGHI has included open and arthroscopic capsulorrhaphy procedures, and more recently thermal capsulorrhaphy, to address this pathoanatomy.[2, 6, 7] Open procedures have traditionally been the preferred method of treatment, an opinion based primarily on the low soft dislocations, ranging from success rates limiting recurrence of 1% to 10%.[6, 36, 48, 65, 69, 74, 81, 82] However, a diminished capacity to return to high-level activity and loss of motion from over-constraint are unresolved concerns associated with open procedures.[4,57, 73, 79]

Arthroscopic techniques have recently become more prevalent in the treatment of AGHI because of decreased surgical morbidity, less surgical time, and lower levels of postoperative pain.[6, 7, 20, 61] Although current arthroscopic techniques have demonstrated success rates comparable to open stabilization,[6, 7, 12, 20, 61] early failure rates varied widely, from 5% to 60%,[61] and were significantly higher than with open repairs.[65, 71, 78] Some authors continue to recommend open over arthroscopic stabilization for high-contact and overhead athletes.[37]

Arthroscopic thermal capsulorrhaphy is a contemporary method utilizing heat to reduce capsular volume via collagen denaturation.[17, 34, 35, 84] Preliminary studies yielded encouraging results in stabilizing the shoulder[16, 17, 35, 90, 91] and the subsequent clinical use of thermal capsulorrhaphy has likely outpaced controlled trials testing its long-term efficacy. Several reports have now identified substantial deleterious effects on the mechanical, histological, and biochemical properties of collagen following thermal denaturation.[33-35, 84, 96] Wall et al.[96] and Schaeffer et al.[84] have demonstrated increased collagen extensibility in animal models, causing specimens to stretch beyond original length under mechanical stress. Severe complications such as osteonecrosis, chondrolysis,[47, 72] and arthrofibrosis[21, 47, 72] have been reported after thermal denaturation of collagen tissue. Increased failure rates have resulted,[8, 16, 58] raising concern over the continued use of thermal energy in arthroscopic stabilization procedures.

Conversely, Hecht et al.[35] noted that while radiofrequency energy altered the stiffness of capsular tissue in an ovine model, the treated tissue began to approach normal stiffness at 6 to 12 weeks after surgery. Using electron microscopy, Hecht and colleagues observed normal collagen appearance 12 weeks after surgery.

While capsuloligamentous structures guide joint kinematics by providing mechanical restraints to external stress,[50, 64, 65] the shoulder also relies heavily on proprioceptive feedback mechanism to maintain dynamic joint stability.[64] Proprioceptive mechanoreceptors have been identified in the glenohumeral capsule, functioning to enhance joint stability by providing important sensory information regarding joint movement and position sense.[46, 94, 97] Tibone demonstrated the existence of an afferent feedback arc in human shoulders.[92] Disruption of this mechanism has been implicated in diminished proprioception following shoulder dislocation.[40, 46, 86, 94, 97] which may inhibit normal reflexive stabilization of the joint, creating a recurrent functional instability.[19, 59, 73, 86]

The effects of surgical treatment of AGHI on shoulder proprioception and rotator cuff strength are not well documented. Several investigators[40, 46, 73,98] have hypothesized that surgical retensioning of glenohumeral capsuloligamentous structures restores joint proprioception and reflexive neuromuscular control. Pollock[73] recently concluded that the best type of capsular reconstruction for preserving proprioceptive structures remains unknown. To date, only one prospective study has examined glenohumeral joint proprioception before and after arthroscopic and open capsulorrhaphy.[75] Lephart et al.[46] and Warner et al.[98] each observed no significant differences in JPS between surgically repaired and the contralateral uninvolved shoulders in a combined group of patients who underwent arthroscopic or open stabilization for AGHI. Additionally, normalized proprioception was demonstrated after thermal repair;[45] however, the mean follow-up period was only 12 months. The long-term effects of thermal collagen denaturation on glenohumeral articular proprioceptors are not currently known.[93]

Rotator cuff strength data have focused on healthy participants, or those with instability and impingement,[98] with few studies examining postoperative strength in repaired subjects.[15, 31, 32, 98] Ellenbecker and Matallino[15] observed comparable rotator cuff strength in involved versus uninvolved shoulders at 12 weeks after thermal capsulorrhaphy. Hartsell[32] demonstrated similar results at 32 months in patients treated with “Bankart-type” anterior stabilization.

We could find no published studies that have directly compared proprioception, strength, and functional outcomes after open, arthroscopic, and thermal capsulorrhaphy procedures. The purpose of this study was to compare glenohumeral joint position sense, isokinetic internal and external rotation strength, functional ability, and level of satisfaction in patients who underwent these common capsulorrhaphy procedures, comparing them to healthy, age-matched controls. Our hypotheses were that the postoperative outcomes of patients in the three surgical groups would not differ significantly, and that objective measures of patient function would correlate highly with postoperative level of satisfaction.

MATERIALS AND METHODS

Subjects and Experimental Groups

A total of 73 adults (44 men, 29 women; mean age 23.7 ± 6.8 years) volunteered to participate in this study. Fifty-four patients who underwent repair of chronic, recurrent, anterior shoulder instability were referred to the study by their surgeon; 51 of these patients (34 men, 17 women) met the criteria for participation in the study.

The criteria for surgical subjects were: (a) no history of concomitant glenohumeral impingement or rotator cuff pathology, (b) full discharge from postoperative rehabilitation, (c) physician clearance for return to activity and/or employment, and (d) a normal contralateral shoulder. When a normal shoulder was not achievable, i.e., the patient had bilateral instability, no statistical comparison was made with the repaired shoulder.

Four experimental groups were formed including three surgical groups and a control group. *Group 1: Open Capsulorrhaphy (OC)* included 21 subjects (17 men, 4 women; mean age, 27.5 ± 9.6 years) who underwent either open capsular shift/suture plication, and/or Bankart repair. *Group 2: Arthroscopic Thermal Capsulorrhaphy (TC)* included 16 subjects (7 men, 9 women; mean age, 21.0 ± 2.0 years) who underwent thermal capsulorrhaphy. *Group 3: Arthroscopic Capsulorrhaphy (AC)* included 14 subjects (10 men, 4 women; 20.2 ± 1.2 years) who underwent arthroscopic suture plication and/or Bankart repair. *Group 4: Controls* included 22 healthy control subjects (11 men, 11 women, mean age, 23.8 ± 5.7 years) with no history of shoulder injury. Control subjects were sex and age-matched in an effort to minimize the confounding effects of age on proprioception.[52, 101]

Clinical examination verified that no shoulder pathology existed in any of the Control group subjects. We obtained the operative reports, including postoperative diagnoses, for every surgical patient. This enabled us to confirm that no additional shoulder pathology beyond that specified for admission to the study was present. Utilizing this postoperative diagnostic information, the data from three individuals with multidirectional instability were excluded from our analysis.

Data Collection

Surgical patients were tested at an average of 32.1 ± 24.8 months postsurgery; range, 6 to 96 months. Prior to participating in the study, subjects provided informed consent as outlined by our Institutional Review Board for the Protection of Human Subjects. Both shoulders of all surgical patients were evaluated by one of us (JAS) using the American Shoulder and Elbow Surgeons' Shoulder Evaluation Form (ASES).[77] In addition, these subjects quantified their level of satisfaction with the repaired shoulder by completing the Shoulder Rating Questionnaire (SRQ) (L'Insalata et al; 2002).

Joint Position Sense (JPS) Protocol. We assessed glenohumeral joint position sense by employing a reproduction of passive positioning protocol with an isokinetic dynamometer (Biodex MultiJoint System 3 Pro^{TM}, Biodex Medical, Inc., Shirley, NY). A custom-designed shoulder positioning device secured the subject's limb to the dynamometer (Figure 1). Prior to testing, each subject's maximum passive external rotation range of motion (ER_{max}) was measured bilaterally while seated in the dynamometer's chair, with the shoulder in 90° abduction and neutral rotation. Two relative target angles were then calculated to evaluate JPS for each subject, based on 60% and 90% of the ER_{max} value in each shoulder. Two previous studies have used a joint position sense testing protocol similar to ours to establish target positions.[38, 88]

A single practice trial was performed on each limb to acquaint subjects with the JPS testing protocol. To begin testing, subjects were blindfolded while seated on the dynamometer with their 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 5" wide stockinette was placed over the subject's arm, and an upper-extremity vacuum splint (Cramer Products, Inc., Gardner, Kansas) was applied and inflated evenly over the stockinette covering the fingers to the mid brachium. The splinted limb was then secured to the dynamometer's lever arm with a 6" elastic bandage. After a standardized warm-up acquainting the subject with the dynamometer the continuous passive motion (CPM) mode of the dynamometer was employed for JPS testing.

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

The dynamometer's software allowed us to quantify the accuracy of reproduction of the target angle to the nearest degree. Joint position sense accuracy was calculated as the absolute difference (in degrees) between the target angle and the joint position identified by the subject. The results of the 3 trials at each angle were averaged to represent the absolute target error for each of the JPS tasks.

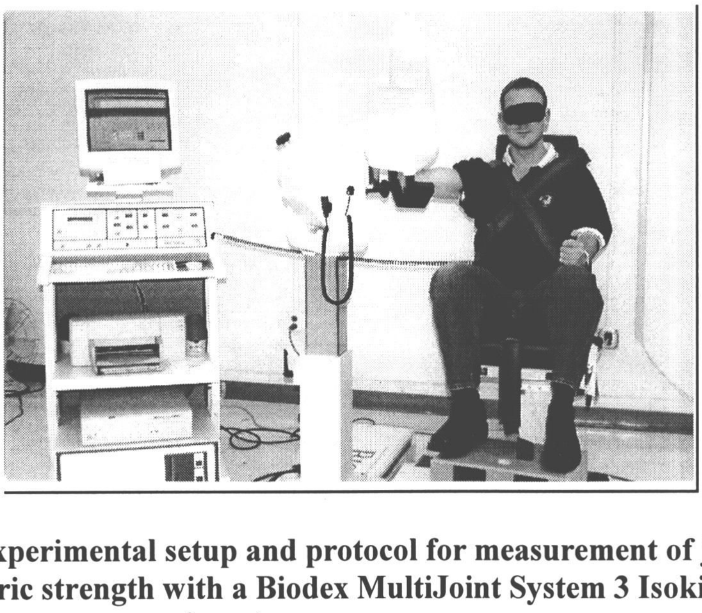


Figure 1. Experimental setup and protocol for measurement of joint position sense and concentric strength with a Biodex MultiJoint System 3 Isokinetic Dynamometer (joint position sense setup shown).

Glenohumeral Muscular Strength Protocol. After joint position sense testing, subjects were seated on the dynamometer in a resting position with the arm in 90° abduction and 90° elbow flexion (the "90-90" position) with neutral rotation in the scapular plane (Figure 1). Concentric internal rotation (IR) and external rotation (ER) peak torque was measured using 5 maximal testing repetitions at 90°/sec, 180°/sec, and 270°/sec. Peak torque values (Nm) were normalized to body weight (kg) to allow for comparisons between male and female subjects of different morphological sizes and physiological capacities.[13] Agonist/antagonist peak torque ratios (external/internal rotators) were obtained from the concentric strength data at each velocity.

Prior to testing, subjects performed a 10-minute warm up session on an upper-body stationary ergometer (Monark Rehab Trainer 881E, Varberg, Sweden) at a submaximal level (50-60 RPMs). To orient subjects with the dynamometer testing protocol, 3 submaximal repetitions of IR/ER were performed at each testing velocity. The dynamometer's gravity correction software feature was employed since gravity could influence the internal rotation (overestimate) and external rotation (underestimate) strength values. Using standardized patient and dynamometer positioning, verbal commands, and testing protocol, the untreated shoulder was evaluated first, followed by the surgically repaired shoulder. The order of testing was counterbalanced between dominant and nondominant shoulders in Control subjects. The single highest peak torque value obtained from 5 maximal repetitions at each testing velocity was used for statistical analysis.

Experimental Design and Statistical Analysis

Prior to statistical analysis, the proprioception, strength and patient satisfaction data were examined for fit between their distributions and the assumptions of ANOVA. The JPS data from one subject in the OC group was identified as an outlier, i.e., greater than 3.3 standard deviations from the group mean, and was removed from the analysis.[89]

An issue with multicollinearity was a concern in the glenohumeral concentric strength measures as these values were highly correlated ($r = 0.73$ to 0.98). Therefore, a decision was made to perform separate mixed-design ANOVAs with repeated measures in order to maximize the explanatory power of each dependent variable, i.e., internal and external rotation peak torque at each of the three testing velocities, toward explained common variance among treatment groups. Mauchly's test revealed a significant departure from sphericity ($P < .003$) in concentric strength outcome measures. As the violation was not severe ($\varepsilon = .84$), the Huyhn-Feldt adjusted values were used to examine differences.

Alpha levels were adjusted for each set of analyses separately examining strength ($0.05/ 4 = .0125$) and proprioception ($0.05/ 2 = .025$) using the Bonferroni correction in order to protect against inflated Type I error rate. In the presence of significant main effects, we employed Scheffé post-hoc tests to delineate the location of mean differences ($P = .05$).

Joint Position Sense Analysis. Two 4 x 2 (Group x Position) mixed-design ANOVAs with repeated measures were conducted to examine the effects of experimental group (Control, OC, AC, TC) and target position (60% ER_{max} and 90% ER_{max}), as well as Group and Limb (involved/uninvolved) on joint position sense.

Isokinetic Strength Analysis. To compare involved limbs between surgical groups, separate 4 x 3 (Group x Velocity) ANOVAs with repeated measures were conducted for internal and external rotation peak torque (Nm)/percentage of body mass (kg) ratios. To compare involved and uninvolved limbs, separate 4 x 2 x 3 ANOVAs (Group x Limb x Velocity) with repeated measures were performed. The strength in the non-dominant limbs of the Control group was compared with the strength of the surgical groups' operative limb. This decision was based on significant strength differences reported between dominant/nondominant limbs of normal (uninjured) subjects.[98]

Patient Outcomes. Pearson product-moment correlation coefficients were calculated to determine relationships between the 100-point, objective ASES shoulder evaluation form and 100-point, subjective SRQ ($P < .05$).

RESULTS

Joint Position Sense

Significant group differences were revealed ($F_{(3,65)}=6.07$, $P < .002$, $\eta^2 = .22$) in mean target angle error, i.e., the average of 60% ER_{max} and 90% ER_{max}. Subjects in the OC group demonstrated significantly less mean JPS error than the AC and Control subjects (Table 1). Post-hoc analysis revealed the JPS accuracy at 60% ER_{max} with OC subjects was significantly better than Controls (4.8° $\pm$ 2.3° versus 8.1° $\pm$ 4.0°, respectively; *Scheffé* $P < .004$) and AC subjects (4.8° $\pm$ 2.3° versus 8.9° $\pm$ 3.4°, respectively; *Scheffé* $P < .011$) (Figure 2). The Group factor explained 22% of the common variance in JPS between subjects. No significant differences were evident between groups at the 90% ER_{max} target angle ($F_{(3,65)} = 1.43$, $P = 0.24$; $1\text{-}\beta = .42$) (Figure 2).

Joint position sense was not significantly different between the repaired and contralateral normal limbs at either target position (*P* ≥ 0.55; 1-β = .10) (Table 2). The mean absolute target reproduction error for all involved shoulders was 7.2° ± 2.9° versus 7.1° ± 4.2° at 60% ER_{max} and 4.3° ± 1.8° versus 4.6° ± 1.9° at 90% ER_{max}.

Significant differences were revealed between target positions ($F_{(1,65)} = 25.14$, $P < .001$) collapsing mean JPS error across groups. Reproduction error was significantly less ($P < .001$) at 90% ER_{max} (4.5°± 2.5°) than at 60% ER_{max} (6.7°± 3.5°) (Figure 3). The Position factor explained 28% of the variance in JPS.

In general, there was a trend toward undershooting the target position as 66% of subject trials undershot and 34% overshot the target position. Subjects exactly matched the target position in 6 trials at 60% ER_{max} and in 23 trials at 90% ER_{max}.

Table 1. Joint position sense for surgically repaired shoulders versus controls. All values are expressed as average absolute error (in degrees) ± standard deviation for angle-reproduction tasks.

	GROUP				
TARGET POSITION	Open (n=20)	Arthroscopic (n=11)	Thermal (n=16)	Controls (n=22)	**Grand Mean (n=69)**
60% ERmax	4.8 ± 2.3*	8.9 ± 3.4*	5.6 ± 2.4	8.1 ± 4.0*	6.7 ± 3.5‡
90% ERmax	3.6 ± 1.7	4.7 ± 3.0	4.7 ± 2.2	5.1 ± 2.9	4.5 ± 2.5‡
Mean JPS error:	4.2 ± 1.9†	6.8 ± 3.2†	5.2 ± 2.3	6.6 ± 3.5†	

* Significant differences in JPS accuracy between OC versus AC ($P \leq .01$), and Controls ($P \leq .004$) at 60% ER_{max}.
† OC group significantly better JPS accuracy than AC and Control across positions ($P \leq .01$)
‡ Significant differences between target positions ($P < .001$).

Table 2. Joint position sense in involved vs. uninvolved limbs at mid-range and end-range of external rotation. No significant differences between involved and uninvolved limbs across experimental groups.

		60% ERmax (°)	90% ERmax (°)
GROUP	*LIMB*	*Mean ±SD*	*Mean ±SD*
OC (n=19)	Involved	5.6 ± 3.3	3.5 ± 1.8
	Uninvolved	6.6 ± 3.9	3.6 ± 1.9
AC (n=6)	Involved	9.9 ± 3.0	4.7 ± 1.0
	Uninvolved	8.4 ± 5.8	5.0 ± 1.2
TC (n=11)	Involved	6.0 ± 2.3	4.7 ± 2.5
	Uninvolved	6.4 ± 2.9	5.1 ± 2.7
Total (N=58):		6.4 ± 3.3	4.4 ± 2.4*
		6.8 ± 4.0	4.2 ± 2.2*
		P = .95	P = .87

* Involved and uninvolved limbs significantly better ($P \le .001$) at 90% ER$_{max}$ versus 60% ER$_{max}$.

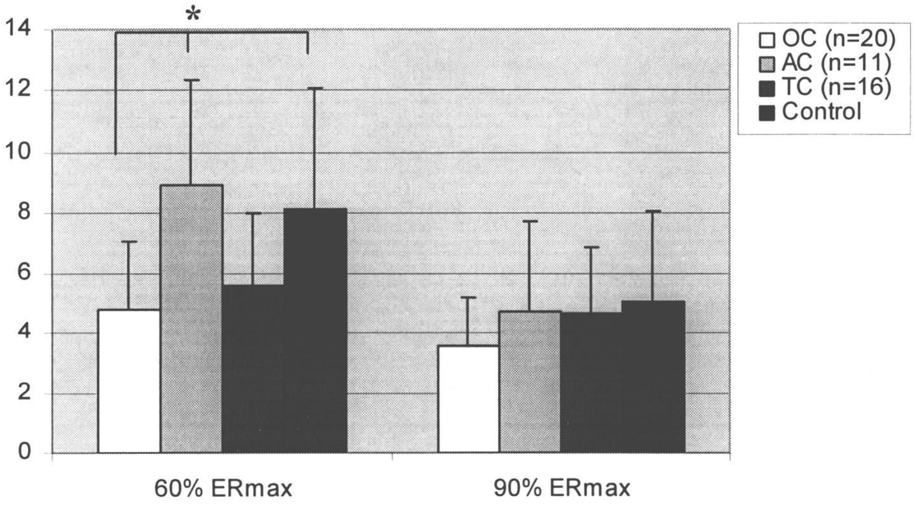


Figure 2. Joint position sense in repaired shoulders and controls at mid-range and end-range of external rotation.

* Significant difference between OC and AC ($P \le .01$) and between OC and Control ($P < .004$) groups.

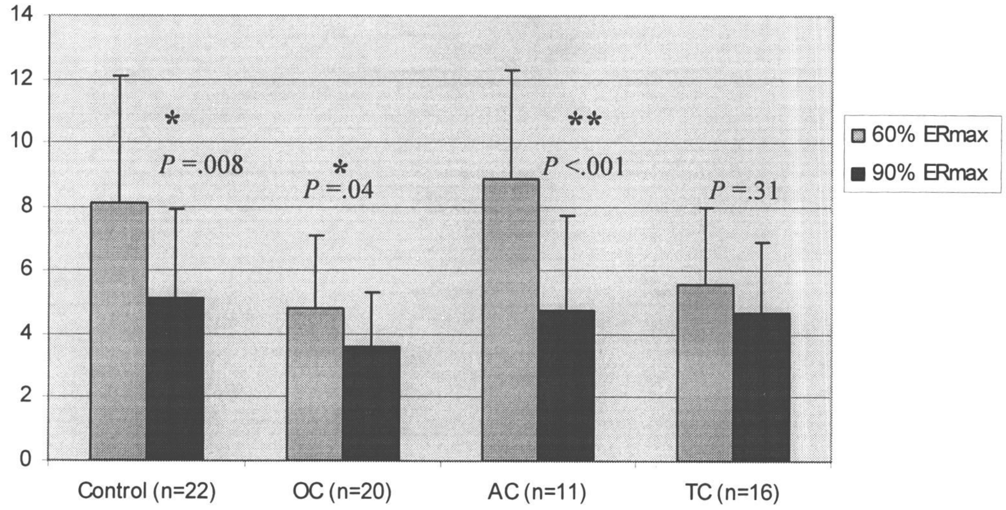


Figure 3. Accuracy of joint position sense at 60% ERmax and 90% ERmax.

* Significantly less mean error ($P < .001$) at 90% ERmax.

** Significantly less mean error ($P < 05$) at 90% ERmax.

Glenohumeral Joint Strength

Strength by Experimental Group. Analysis of concentric peak torque/ body mass ratios demonstrated significant group differences in internal rotation ($F_{(3,65)} = 7.1$, $P \leq .001$, $\eta^2 = .23$) and external rotation strength ($F_{(3,65)} = 4.4$, $P < .01$, $\eta^2 = .17$) (Figure 5). Bilateral peak torque group means and standard deviations are presented in Tables 3 and 4. A significant Group x Velocity interaction ($F_{(6, 128)} = 3.0$, $P \leq .01$, $\eta^2 = .13$) was present for internal rotation strength (Figure 4). Scheffé post-hoc analysis delineated the following group differences:

Open group. OC subjects' involved limbs had significantly less internal rotation strength (31% mean deficit) than Controls ($P = .007$), and AC subjects (33% deficits; $P \leq .013$) across testing velocities (Figure 5). OC subjects also demonstrated less ER strength than AC subjects ($P \leq .0125$) and controls' dominant limbs ($P = .003$) at 270°/sec (Figure 6).

Thermal group. TC subjects' involved limbs demonstrated no significant differences in internal or external rotation peak torque across testing velocities versus OC subjects ($P = .92$ and $P = .87$, respectively) versus AC subjects' ($P = .13$, and $P = .63$, respectively), or versus healthy controls' nondominant limbs ($P = .03$, and $P = .10$, respectively) (Figure 5). However, examination by testing velocity revealed significant involved limb internal rotation deficits at 90°/sec versus AC subjects ($P \leq .013$) (Figure 5).

Arthroscopic group: AC subjects had greater internal rotation peak torque values than OC subjects ($P \leq .013$), but not TC subjects ($P = .13$) or Controls ($P = .99$) (Figure 5).

Involved versus uninvolved limbs. Uninvolved limbs had significantly higher mean peak torque internal rotation values (46.7 $\pm$ 16.6 Nm/kg, respectively) than involved limbs (43.6 ± 15.7 Nm/kg) collapsing across groups and velocities ($F_{(1,52)} = 6.5$, $P < .013$, $\eta^2 = .12$) (Figure 8). Simple nested effects revealed that OC subjects' involved limbs generated significantly less torque in internal rotation (39.4 ± 3.5 Nm/kg) than their uninvolved limbs (51.3 ± 4.4 Nm/kg; $P = .002$, $\eta^2 = .45$) (Figures 8 and 10). External rotation torque values were significantly higher in the nonsurgical shoulders (36.0 ± 11.3 Nm/kg) than the surgical shoulders (33.5 ± 11.6 Nm/kg) ($F_{(1,31)} = 11.8$, $P = .002$, $\eta^2 = .28$) (Table 3). AC subjects demonstrated the largest involved-limb deficit (12%) in ER, although not significant ($P = .08$; $1\text{-}\beta = 0.74$) (Figure 11). Also, a significant *Limb x Group* interaction was revealed for internal rotation ($F_{(3,52)} = 4.6$, $P < .006$, η^2=.21) across testing velocities.

External rotation/Internal rotation (ER/IR) strength ratios. Significant group differences were observed in strength ratios at 90°/sec ($F_{(3,65)} = 4.4$, $P = .007$); AC subjects demonstrated significantly better ratios than OC subjects (75.1 ± 10.3 versus 96.2 ± 25.9; *Scheffe΄*, $P < .03$) (Figure 9). Velocity significantly affected strength ratios ($F_{(2,62)} = 5.1$, $P = .009$, $\eta^2 = .14$), as ratios were higher ($P = .004$) at 90°/sec than at 270°/sec in all groups (87.9 ± 19.6 versus 81.4 ± 17.7 Nm/Kg, respectively).

Strength by testing velocity. Consistent with the principles that govern the concentric force/velocity relationship, overall group mean peak torque/body weight ratios were significantly different among testing velocities ($F_{(1.8,62)} = 27.06$, $P < .001$; $\eta^2 = .31$) External rotation peak torque values were significantly greater in all groups at 90° versus 180°/sec ($P < .001$), and also at 90° versus 270°/sec ($P < .001$), but not at 180° versus 270°/sec ($P = .57$). Internal rotation strength was also significantly greater in all groups at 90° versus 180°/sec only ($P < .001$, $\eta^2 = .21$). The Group factor explained 23% and the Velocity factor explained 31% of the variance in the strength outcome measure.

Table 3. Bilateral comparison of means, standard deviations, and percent deficits of external rotation glenohumeral joint strength. [Values expressed are mean peak torques (Nm) as a percentage of body mass (kg) across testing velocities.]

	EXTERNAL ROTATION PEAK TORQUE			
GROUP	**LIMB**	**Mean** (Nm/kg)	**S.D.** (± Nm/kg)	**% Deficit**
Open (n=18)	Involved	32.2	12.6	10%
	Uninvolved	35.5	12.7	
Thermal (n=11)	Involved	36.3	10.2	<1%†
	Uninvolved	36.1	8.9	
Arthroscopic (n=5)	Involved	32.4	12.6	12%
	Uninvolved	36.8	13.2	
Control (n=22)	Nondominant	42.1	10.6	+3%†
	Dominant	40.8	9.3	

† Positive value indicates involved or dominant shoulder stronger than uninvolved/nondominant.

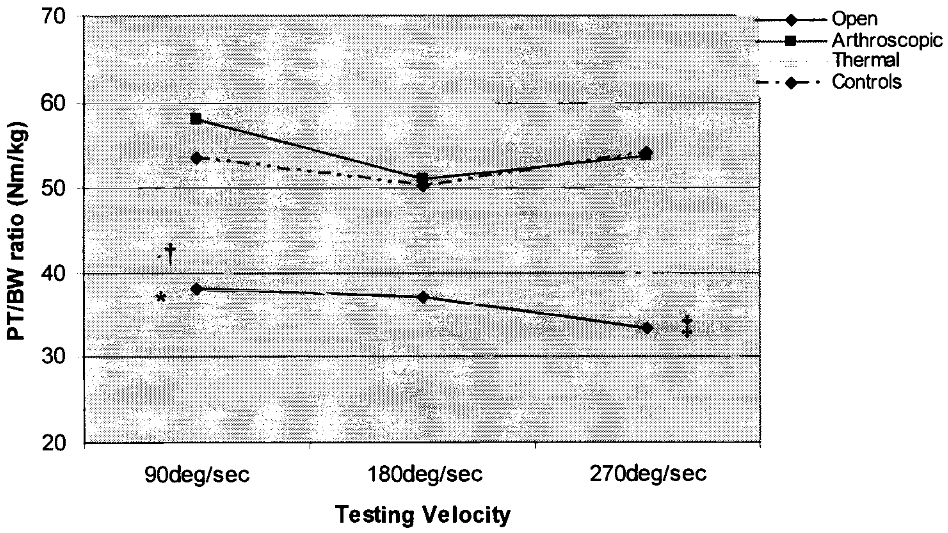
Table 4. Bilateral comparison of means, standard deviations, and percent deficits of internal rotation glenohumeral joint strength. [Values expressed are mean peak torques (Nm) as a percentage of body mass (kg) across testing velocities.]

	INTERNAL ROTATION*			
GROUP	LIMB	Mean (Nm/kg)	S.D. (± Nm/kg)	% Deficit
Open (n=18)	Involved	37.5	17.5	20.0%**
	Uninvolved	46.7	21.2	
Thermal (n=11)	Involved	42.5	13.8	1.6%
	Uninvolved	43.2	14.6	
Arthroscopic (n=5)	Involved	42.0	17.6	5.4%
	Uninvolved	44.4	15.4	
Control (n=22)	Nondominant	52.7	13.8	+1% †
	Dominant	52.2	15.1	

** Significant involved-limb deficit ($P < .013$)

† Positive value indicates involved or dominant shoulder stronger than uninvolved/nondominant.

Figure 4. Group-by-Velocity Interaction for Internal Rotation Strength (Peak Torque/ Percentage of Body Mass) in Surgical Patients and Controls.



* Open significantly different than arthroscopic group ($P \leq .013$) at 90°/sec.

† Thermal significantly different than arthroscopic group ($P \leq .013$), but not Controls ($P = .03$) at 90°/sec.

‡ Open significantly different than arthroscopic ($P \leq .013$) and Controls ($P \leq .001$) at 270°/sec.

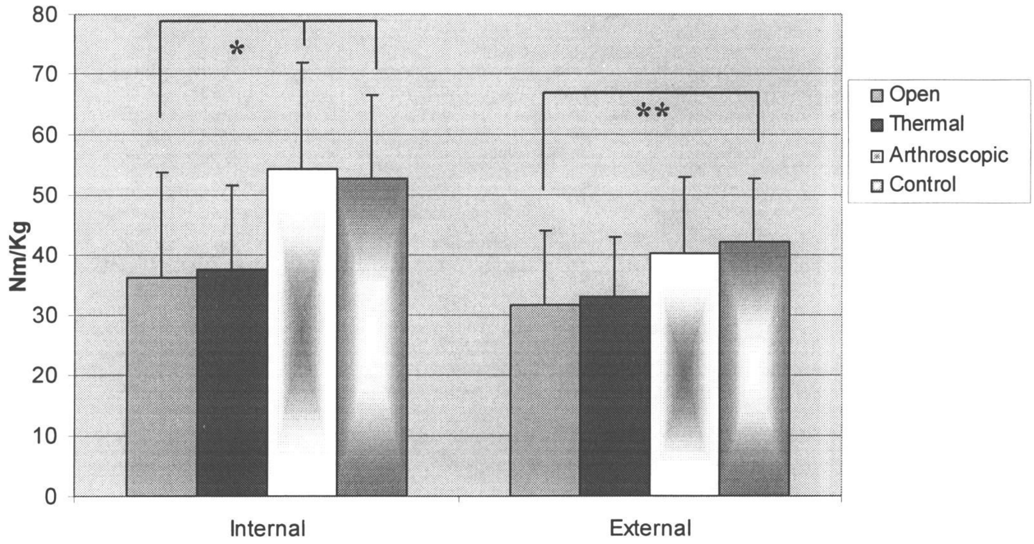


Figure 5. Involved limb internal and external rotation mean strength across testing velocities. Values expressed as peak-torque-(Nm)-to-percentage of body mass (kg) ratios.

* Open significantly less internal rotation strength than controls ($P < .01$), and Arthroscopic ($P \leq .0125$).

**Open significantly less external rotation strength than Controls ($P \leq .02$).

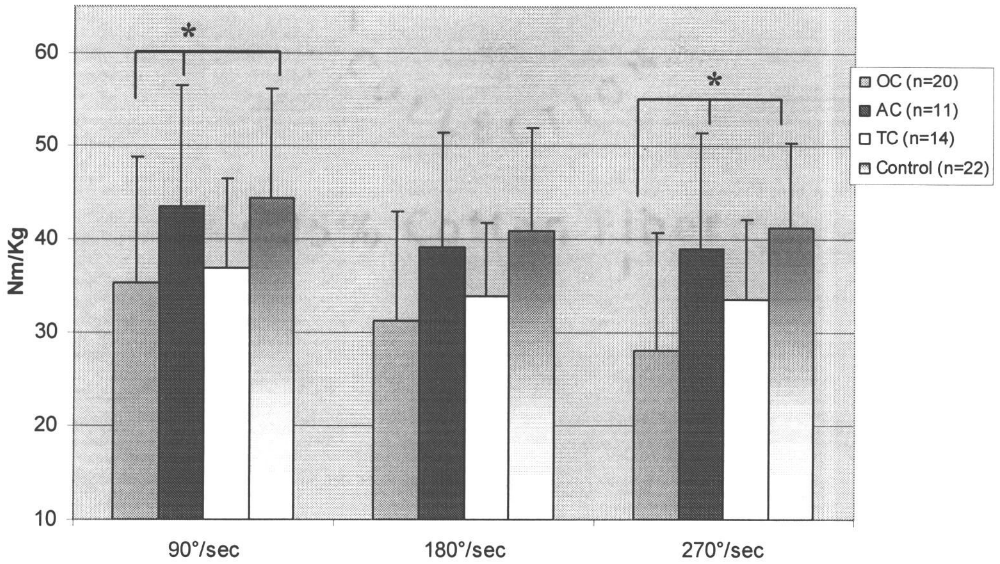


Figure 6. Involved limbs' external rotation concentric strength (PT/BW) ratios.
* OC patients had significantly less torque than AC patients and Controls' nondominant limbs at 90° and 270°/sec (P < .013).

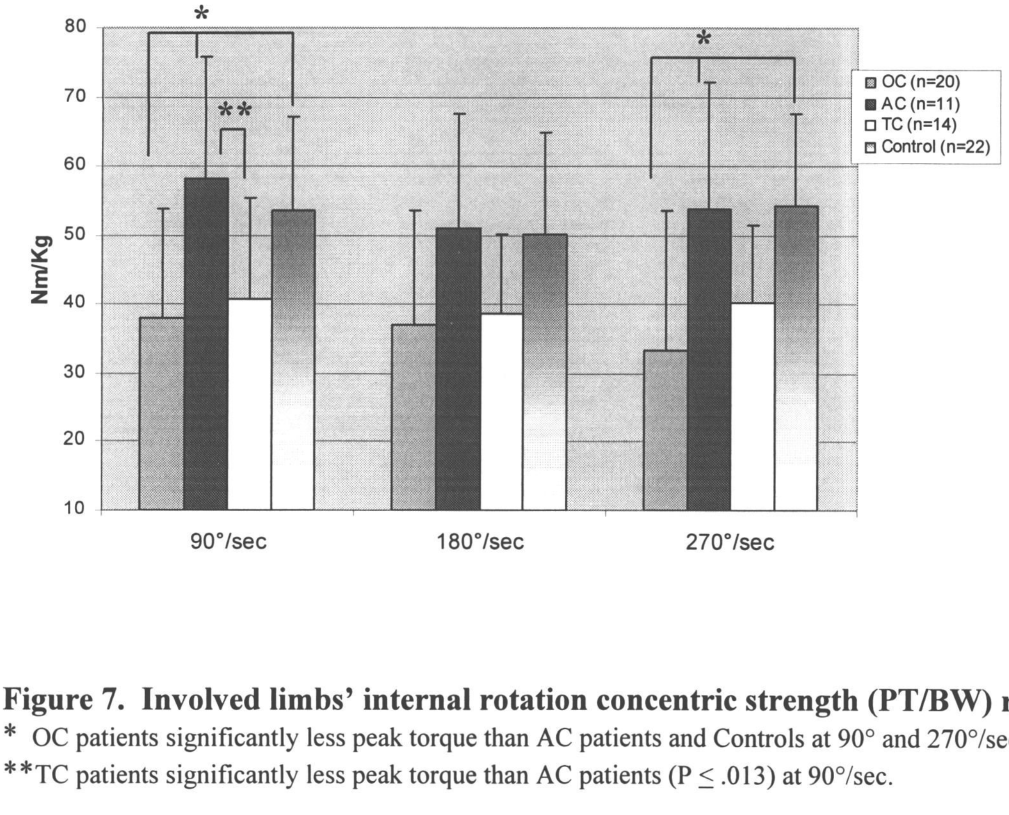


Figure 7. Involved limbs' internal rotation concentric strength (PT/BW) ratios.
* OC patients significantly less peak torque than AC patients and Controls at 90° and 270°/sec (P ≤ .0125.
**TC patients significantly less peak torque than AC patients (P ≤ .013) at 90°/sec.

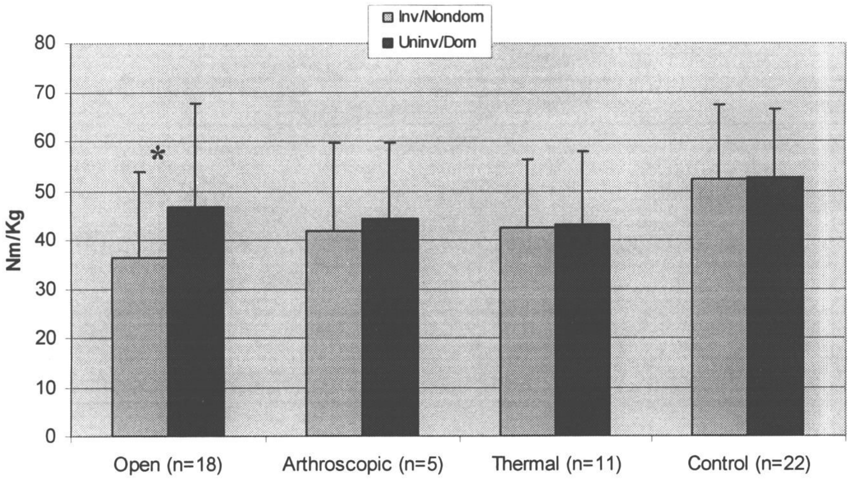
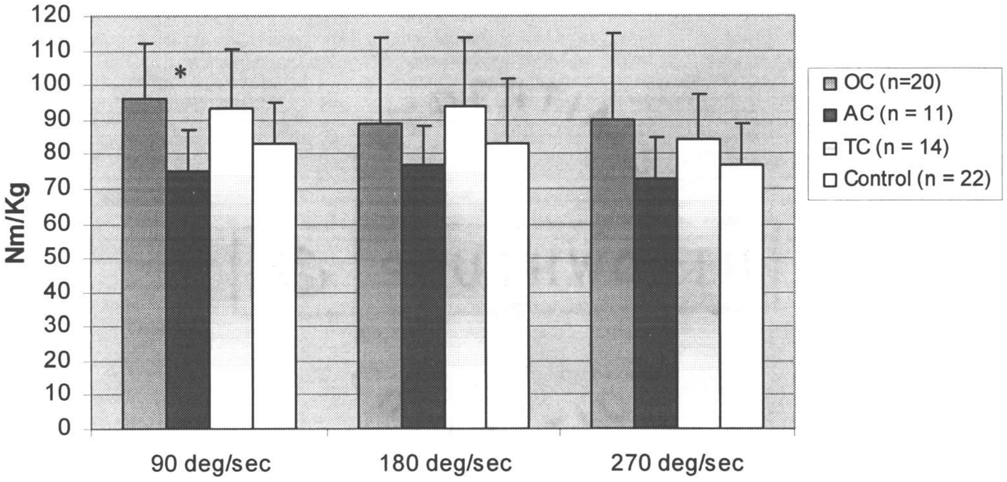


Figure 8. Involved versus uninvolved limbs in mean strength. (A) Internal rotation glenohumeral joint strength. [Values expressed are mean peak torques (Nm) as a percentage of body mass (kg) across testing velocities.]

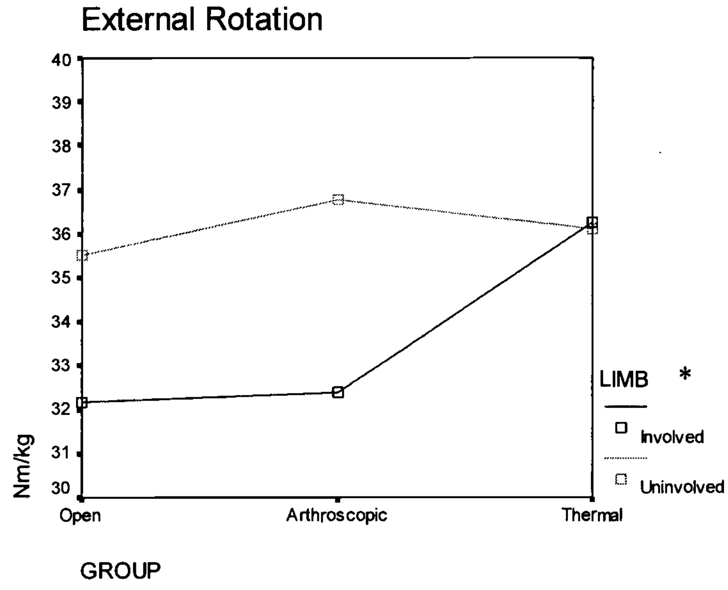
* Significant involved-limb deficit in IR (*P* < .01).

Figure 9. Involved limb strength ratios (external/internal rotation) by testing velocity.



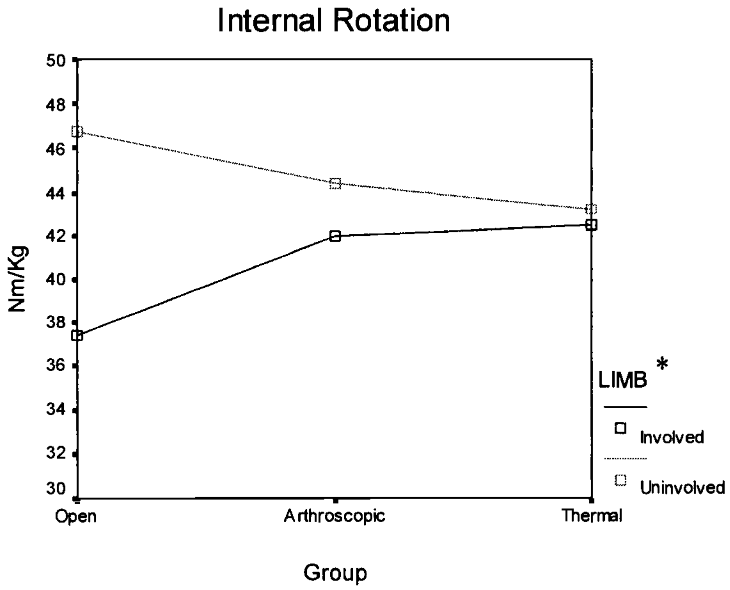
* Significant difference between OC and AC subjects (P < .01).

Figure 10. External rotation peak torque values in surgical limbs versus uninvolved limbs.



* Significant involved-limb deficit (P < .001).

Figure 11. Internal rotation peak torque values in surgical limbs versus uninvolved limbs.

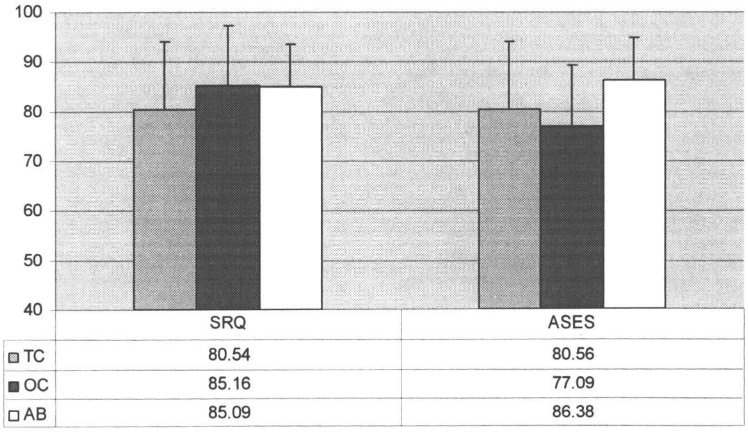


* Significant involved-limb deficit (P ≤ .001). Open subjects = 20% involved-limb deficit.

Shoulder Evaluation Form (ASES) and Shoulder Rating Questionnaire (SRQ)

No significant differences were observed among surgical groups in mean Shoulder Evaluation Form (ASES) ($P = .10$; $1\text{-}\beta = 0.43$) or Shoulder Rating Questionnaire (SRQ) scores ($P = .49$; $1\text{-}\beta = 0.17$) (Figure 12). Control subjects did not complete the ASES or SRQ forms as they possessed "normal", uninjured shoulders. The overall functional score obtained on the SRQ was 83.90 ± 11.63 points out of 100 possible, suggesting that normal function and satisfaction were achieved on average in each group (Figure 13). The overall ASES evaluation form score was "satisfactory" to "excellent" (80.55/100 ± 12.94 points).

A significant, moderately high correlation ($r_{(46)} = .640$; range = .42 to .92; $P \leq .001$) existed between the Shoulder Evaluation Form (ASES) and the Shoulder Rating Questionnaire (SRQ) scores (Table 5).



	SRQ	ASES
▨ TC	80.54	80.56
■ OC	85.16	77.09
☐ AB	85.09	86.38

Figure 12. Shoulder Rating Questionnaire and ASES Shoulder Evaluation Form outcome scores by surgical group.

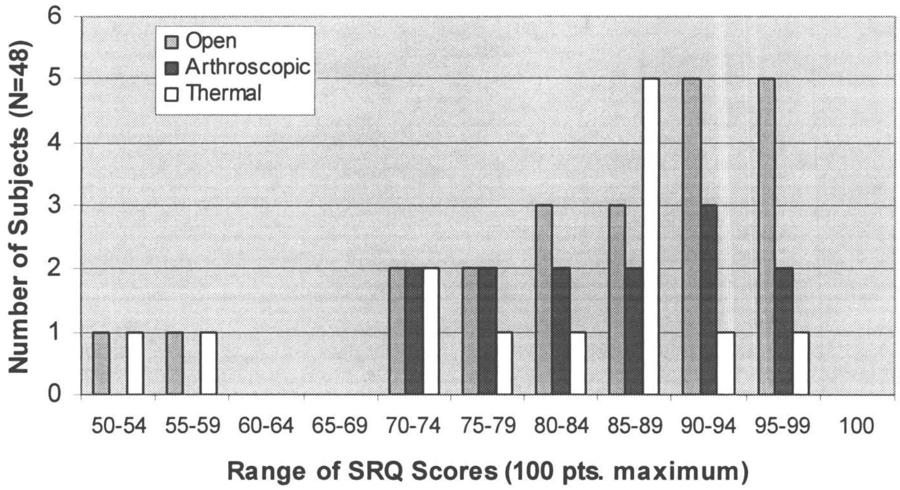


Figure 13. Range (Distributions) of SRQ scores among surgical groups.

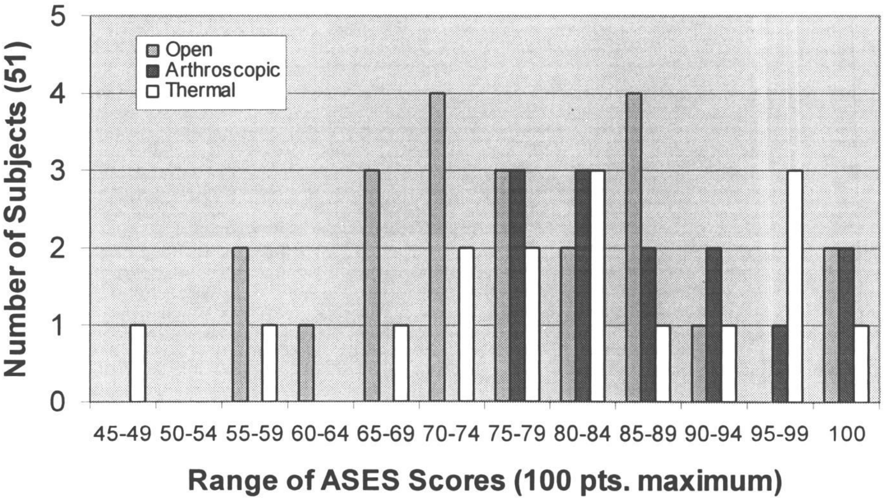


Figure 14. Range (Distributions) of ASES scores among surgical groups.

Table 5. Correlations between objective and subjective outcomes.

	Shoulder Rating Questionnaire (n = 48 shoulders)		
	Thermal	Arthroscopic	Open
ASES Evaluation Form (n = 51 shoulders)	r = .92 (P < .001)	r = .60 (P = .038)	r = .42 (P = .050)

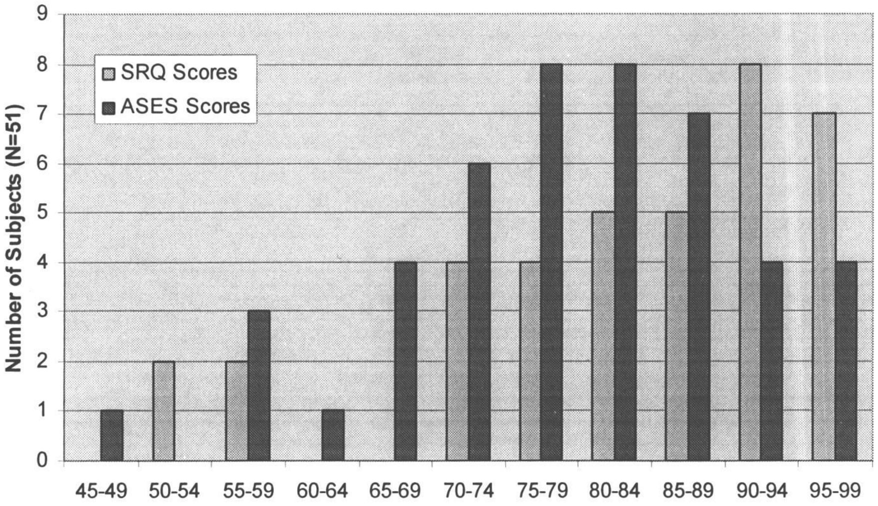


Figure 15. Distribution of ASES and SRQ scores among surgical patients, collapsed across surgical groups (100 pts. maximum).

DISCUSSION

Joint Position Sense Data

Our findings support the hypothesis that surgical retensioning of the anterior capsule and musculature enhanced proprioceptive feedback at the glenohumeral joint and restored the accuracy of glenohumeral joint position sense to that of the patient's contralateral normal limb, irrespective of operative technique. These findings are consistent with previous reports in surgically-repaired shoulders.[4, 45, 46, 75, 86, 95, 101]

Lephart et al.[46] assessed reproduction of passive positioning (RPP) in a combined group of postsurgical open and arthroscopic glenohumeral capsulorrhaphy patients, and later examined these same parameters in a group of glenohumeral thermal capsulorrhaphy patients.[45] In both studies, a "normalization" of shoulder proprioception was reported postoperatively, with no significant differences measured between the patients' involved and uninvolved limbs. Lephart and associates[45] reported RPP results of 1.6° to 2.7° in the repaired shoulders and 1.9° to 2.5° in the uninvolved shoulders of thermal capsulorrhaphy patients. These authors earlier observed RPP values of 2.0° to 3.5° in patients treated with open and arthroscopic capsulorrhaphy.[46] While these values are lower than those observed in our patient sample, the design of Lephart's studies did not allow for direct statistical comparison between open, arthroscopic, and thermal capsulorrhaphy subjects.

We included an age- and sex-matched control group in our study due to recent concerns that the contralateral, uninjured limbs of surgical patients are not appropriate "control" limbs.[75] Some authors[40, 75] have demonstrated that preoperative deficits in proprioception in the affected limb can influence proprioceptive capability of the unaffected, contralateral limb. Our results demonstrated that it was important to have a group of subjects with no injuries to either shoulder, but not for the reasons previously identified in the literature. At the 90% ER_{max} target angle, the Control group had the poorest JPS accuracy, while at the 60% ER_{max} position, only the Arthroscopic group had lower accuracy in the reproduction of passive positioning task. Neither of the previous cited studies by Lephart et al.[45, 46] included comparisons between surgical patients and a control group, so no direct comparisons can be drawn among their studies and ours.

Potzl et al[75] measured active angle reproduction in 14 patients with surgically repaired shoulders (open and arthroscopic) and 15 normal subjects, demonstrating significantly better accuracy in the postsurgical patients. Similar to Lephart et al.[46], Potzl and colleagues[75] did not perform statistical analyses on the differences in joint position sense between the open and arthroscopic surgical groups, most likely due to low sample sizes in each surgical group, i.e., 10 patients with open repairs, 4 patients with arthroscopic procedures.

Tibone et al.[92] provided direct evidence of an afferent feedback arc in human shoulders by monitoring somatosensory cortical evoked potentials through scalp electrodes originating in the glenohumeral joint capsuloligamentous structures and terminating in the cerebral cortex. Interestingly, Tibone and colleagues[92] did not find significant differences in this reflex arc between healthy subjects and those with unstable shoulders. These authors reasoned that proprioceptive deficits after instability are not likely the result of gross damage to neurological elements within the glenohumeral joint, but rather, this afferent pathway remains intact, but it is not being sufficiently activated.

While our results suggest normal activation of this pathway after surgery, the extent to which this occurred cannot be determined due to the retrospective nature of our study.

The patients in the open capsulorrhaphy group demonstrated the best JPS accuracy among all three surgical groups. Pollock[73] recently concluded that the best type of glenohumeral capsular reconstruction for preserving the proprioceptive structures remains unknown. No previous studies have directly compared postoperative joint position sense accuracy in open, arthroscopic, and thermal capsulorrhaphy surgical procedures to address this question. The open capsulorrhaphy patients in our study demonstrated significantly better JPS acuity than Arthroscopic capsulorrhaphy patients and the normal (control) group's dominant shoulders, averaging 2.4° and 2.2° less JPS error, respectively.

Somewhat of a surprise was the lack of differences in JPS between the open and thermal capsulorrhaphy patients. Recent complications associated with thermal denaturation of collagen tissue include capsular ablation, osteonecrosis, chondrolysis,[49, 72] and arthrofibrosis.[21, 72] While these complications have raised concern over increased failure rates in patients treated with thermal capsulorrhaphy[16, 8,58] thermal treatment of glenohumeral capsuloligamentous structures did not appear to deleteriously effect shoulder joint position sense in our sample of patients.

The most likely explanation of the heightened joint position sense in our Open surgical group is through optimal retensioning of a redundant middle glenohumeral ligament and inferior glenohumeral ligament complex (IGHLC) through direct visualization. The restoration of glenohumeral capsular tension is more effectively accomplished with open capsular shift procedures than with arthroscopic techniques.[48, 74,

[79] Gaunche et al.[22] recommended a lateral (humeral) shift procedure to optimally preserve capsular neural supply, while Gohlke et al.[27] advocated a medially-based procedure as best for restoration of capsular architecture. Irrespective of surgical approach, capsular mechanoreceptors are stimulated in proportion to the tension placed on the joint capsule during passive joint rotation, with Ruffini receptors apparently serving as limit detectors, responding to joint movements approaching end range of motion.[29] In our sample, it appears that open capsulorrhaphy most efficiently restored glenohumeral capsular tension and the capacity to provide feedback related to end-range joint positions.

O'Connor[67] demonstrated that capsular receptors likely play more of a role in protecting unstable joints from injury than in actual joint position sense. O'Connor and colleagues created knee instability in dogs by surgically severing the ACL unilaterally. The authors left articular nerve supply intact in a group of these ACL-deficient dogs, and severed the nerve supply to the ACL-deficient knee in others. At 72 weeks after surgery, the researchers noted that while all ACL-deficient knees showed osteoarthritic changes, the degree of degeneration was greater in the knees with severed nerve supply. Thus, the animals appeared to use afferent information provided by the articular nerves to signal potentially damaging joint positions and to adapt movement strategies in the affected knee to protect the joint.

Generalizing the findings of O'Connor[67] to the shoulder, it would follow that the effects of open repair on receptors located in the anterior musculature may provide a better explanation for improved proprioception in Open capsulorrhaphy patients. Musculotendinous afferent receptors, specifically, golgi tendon organs and muscle-spindle afferents, are tension sensors that are proportionally activated during concentric and eccentric muscular activity as well as during passive elongation.[52, 64] Open repair typically involves anatomic resection of the subscapularis, causing the muscle to shorten and scar. This increases the tension in the muscle during passive external rotation and likely enhances joint position sense by increasing muscle afferent activation.

The extent to which joint position sense returned to normal following surgery is unclear due to the retrospective nature of our study, i.e., we do not know whether preoperative deficits existed. Also unknown is if deficits occurred bilaterally. Interestingly, Potzl et al.[75] noted significant preoperative deficits in proprioception in both the involved and contralateral uninjured limbs, while Lephart et al.[46] reported no significant proprioceptive deficits in uninjured limbs. Using a prospective, longitudinal study design, Potzl et al.[75] reported preoperative bilateral deficits in proprioception in patients with unilateral anterior shoulder instability, and observed a subsequent bilateral improvement following surgical repair at long term follow up (mean = 5.9 years). These authors' findings provide the best evidence demonstrating *restored* proprioceptive acuity after surgical capsular retensioning of the shoulder. Our retrospective postoperative results are in agreement with the Potzl et al[75] conclusions.

We were also surprised by the accuracy with which our thermal capsulorrhaphy patients were able to reproduce the passively placed target angles. While the Open surgical group had the greatest accuracy, the Thermal group's JPS was better than the Arthroscopy and Control groups at both target angles. Given the significant collagen denaturation[60, 33-35, 66, 84, 96] that is known to occur with thermal capsulorrhaphy, one would assume that the capsuloligamentous mechanoreceptors would also be ablated in the denatured glenohumeral joint capsule. However, thermal capsulorrhaphy studies in animal models have shown a return to near-normal biomechanical properties of collagen at 6 to 12 weeks of tissue remodeling,[35] and thus, neural reinnervation could have theoretically occurred. We could find no published studies to support or refute this supposition. Our null hypothesis was supported that Thermal patients would demonstrate an equivocal level of joint position sense in their surgically-repaired shoulders compared to both their contralateral normal shoulders and the uninjured shoulders of age and sex-matched controls. Our results are in agreement with those reported by Lephart et al.[45] who observed equivocal proprioception in the repaired and contralateral shoulders at 12 months following thermal repair. Our findings suggest that bilateral symmetry in shoulder joint position sense was present in thermal capsulorrhaphy patients at an average of 27.5 months postsurgery.

Nonetheless, these findings do not provide evidence of neural repopulation following thermal capsulorrhaphy. While no published studies have evaluated the histological effects of thermal energy on articular mechanoreceptors, insight can be gleaned from other literature evaluating the neural properties of altered human graft tissue.[3, 76] Studies in the knee have demonstrated repopulation of mechanoreceptors in ACL-graft tissue following ACL-reconstruction.[3, 76] However, receptors located in the ACL graft are unlikely to provide the CNS with precision information regarding joint position[30] or movement sense.[29,98] Considering the shoulder, if the glenohumeral joint capsule provides unique information regarding joint position sense, then the capsular denaturation that occurs with thermal capsulorrhaphy should have resulted in significant impairment of proprioception. Our findings of comparable involved/uninvolved limbs in thermal capsulorrhaphy patients refute this notion, and add to the growing body of evidence that mechanoreceptors located in muscles and tendons, rather than articular afferents, are predominantly responsible for position sense acuity in human joints.[28, 29, 39, 42]

Target position. The accuracy of glenohumeral joint position sense was influenced by the degree of external rotation to which the joint was moved during testing. We observed greater joint repositioning accuracy at near-maximal external rotation of the shoulder versus midrange. This result agrees with Janwantanakul,[38] and others[1,4] who reported improved joint position sense[38] and enhanced detection of motion[1, 4] approaching end-range of shoulder joint external rotation. However, Zuckerman and colleagues[101] observed decreased position sense acuity at maximum range of passive glenohumeral abduction, flexion and external rotation. These authors noted that the age of their subjects may have influenced their findings as they observed significantly better acuity in the detection of passive motion in 20 young subjects (20-30 years old) versus 20 older (50-70 years old) subjects.

Variation in the tension of capsular and muscular restraints is the proposed mechanism for inconsistent JPS acuity across a subject's available range of motion. Because capsular and muscular mechanoreceptors are stimulated in proportion to the tension during passive joint rotation, our 90% ER_{max} JPS testing position more effectively activated these receptors.[29, 38 ,98] Capsuloligamentous receptors, e.g., Ruffini endings, likely contributed to detection of end-range of external rotation movement. Studies of the properties of joint afferents in animal models have identified Ruffini endings as limit detectors, serving to signal that the joint is at end-range of motion.[29] In contrast, these receptors play little or no role in appreciating midrange joint positions, such as our 60% ER_{max} target position.[22, 23, 28, 29]

Shoulder Strength Data.

Our null hypothesis that postoperative internal and external rotation strength would not be significantly different among the surgical groups was not supported by our data. Our most significant finding was that the Open capsulorrhaphy patients demonstrated surgical limb deficits of 11% and 28% in internal rotation peak torque compared to Arthroscopic patients and Control subjects, respectively. Similarly, the Open group also had deficits of 21% in external rotation peak torque compared to the Control subjects. The surgically-repaired shoulders of the Open capsulorrhaphy patients generated significantly less internal rotation torque than their contralateral normal shoulders when tested at 90°/sec. In addition, Thermal capsulorrhaphy patients' involved limbs had 30% less internal rotation strength than Arthroscopic patients at 90°/sec.

The large strength deficits present in the Open group, particularly in internal rotation, are a significant concern. The primary objective during rehabilitation following surgical repair of recurrent AGHI is to facilitate patient function by restoring the coordinated action of the force couples of the glenohumeral joint.[5, 99, 100] The internal humeral rotators, including the pectoralis major, latissimus dorsi and subscapularis contribute substantially to glenohumeral stability following anterior shoulder dislocation.[87] In particular, the subscapularis contributes to glenohumeral force couples to counterbalance the teres minor and infraspinatus, and also partners with the infraspinatus and teres minor to oppose the anterior deltoid, providing dynamic glenohumeral joint stability.[41, 87, 99, 100] Any impairment in the stabilizing function of these muscles may lead to greater overload of the static glenohumeral stabilizers, abnormal shear stresses, subluxation, and a resulting secondary impingement syndrome.[5, 11, 64, 78, 87, 99]

Open surgical repair of anterior glenohumeral instability has been demonstrated to be a successful method of treating a variety of capsular and labral pathologies, and a more effective technique for retensioning of a damaged or redundant joint capsule.[25, 37] □In contrast, there are persistent concerns with this technique that include limited external rotation motion due to over-constraint of the capsule, and a decreased ability to return to a highly-competitive level, particularly throwing.[11, 99]

To our knowledge, no previous study has identified long-term concentric internal rotation strength deficits as a concern following open repair of recurrent anterior glenohumeral instability. There are at least three explanations for this observed deficit:

(1) In order to adequately visualize the joint capsule during open repair, the subscapularis is typically divided by vertical tenotomy, detached, and repaired;[81] the subscapularis may also be separated transversely in line with its fibers to limit postoperative restriction in external rotation.[24] Our results suggest that open anatomic resection and scarring of the subscapularis may reduce its strength and limit its contribution to dynamic anterior glenohumeral stability. Since arthroscopic and thermal capsulorrhaphy procedures are less invasive and produce minimal muscle scarring at surgery,[48] this factor perhaps best explains internal rotation strength deficits in Open capsulorrhaphy subjects.

(2) Previous anterior glenohumeral instability may have influenced internal rotation limb strength. Individuals with unresolved, excessive capsular laxity and recurrent instability are often advised toward open repair to maximize stability.[20, 43, 53, 57] Glousman et al.[26] examined pitchers with anterior instability, observing a significant decrease in subscapularis, latissimus dorsi and pectoralis major EMG activity during the cocking and acceleration phases of throwing. Pitchers with normal shoulders demonstrated greater EMG activity in these muscles. In addition, Neviaser et al.[62] noted that a rupture of the subscapularis may occur, and should be expected with recurrent instability, particularly in older patients. Their patients had "mild-to-moderate" deficits in internal rotation following open surgical repair. Although 4 of the 22 (18%) Open capsulorrhaphy patients in our sample had recurrent instability after surgery, i.e., reported as recurrent subluxation (n = 3) or dislocation (n = 1), only 1 case of subscapularis rupture was noted on the operative report. Complete rupture of the subscapularis with anterior dislocation is uncommon, particularly in younger patients.[85]

(3) Limb dominance may also have influenced internal rotation strength. A maximum limb dominance of the internal and external rotators is generally understood to be 5% to 10% in both nonathletes and recreational athletes; bilateral differences of 10% to 15% are considered indicative of significant asymmetry.[15, 63] Limb dominance does appear to be a factor in unilaterally dominant upper-extremity-sport athletes. Ellenbecker and Mattalino[14] observed significantly greater peak torque and total work values in the dominant shoulders of elite baseball pitchers. However, limb dominance does not appear to have confounded our Open capsulorrhaphy group as 47% of these subjects had surgery on the dominant limb compared to 46% of patients in the Arthroscopic group. The Thermal group had a larger proportion (69%) of patients' dominant limbs repaired. This may have positively influenced both the internal rotation and external rotation strength measures of Thermal patients, resulting in the minimal differences (2% in internal rotation and 1% in external rotation) observed between the involved and uninvolved shoulders.

To summarize, it seems reasonable that surgical manipulation of the subscapularis decreased internal rotation strength in our Open capsulorrhaphy patients. Also plausible is that rehabilitation did not adequately address the postoperative internal rotation weakness. This possibility may apply particularly to Thermal patients as debate currently exists on the postoperative rehabilitation of these patients.[15, 17, 93, 99] With the development of procedures using both laser and radiofrequency probes, and the use of varying shrinking techniques including "paintbrush" and "striping/corn row" methods[17, 35, 90, 91] immobilization and strengthening parameters have been imprecise. D'Alessandro and colleagues[8] have suggested that rehabilitation should be diagnosis-specific.

Whether attributed to injury during surgery or insufficient rehabilitation, the internal rotation deficits in Open and Thermal patients likely occurred in the subscapularis muscle. EMG data have identified the subscapularis as the most active internal rotator of the arm in the cocking position, with the latissimus dorsi and pectoralis major serving a lesser role.[5, 11 100] We attempted to mimic the cocking position with our concentric strength testing position, i.e. 90° glenohumeral abduction in 30° scapular adduction. The subscapularis aids in accelerating the humerus in this position, and eccentrically controls external rotation in the cocking phase.[83] □(Some authors[70, 97] hypothesize that repetitive, eccentric overload of the subscapularis results in fatigue and weakness during throwing. In addition, it must be remembered that the subscapularis has an upper and lower portion, each of which is independently innervated.[10] Decker et al.[10]

demonstrated that particular exercises are necessary to strengthen each portion, and optimal activation of one portion may not adequately activate the other. Since postoperative rehabilitation was not standardized among our subjects, its influence on postoperative internal rotation strength is unclear.

Involved versus uninvolved limbs. We hypothesized that limb strength would not be significantly different between the repaired and contralateral normal limbs in all three surgical groups, and that the dominant limbs of subjects in the Control group would generate higher internal and external rotation peak torques than their nondominant shoulders. No significant differences in internal or external rotation peak torque were found between involved and uninvolved limbs of the Arthroscopic or Thermal group patients, or between the dominant and nondominant shoulders of the Control group.

Hartsell and Forwell[32] reported similar results in fifteen patients evaluated 32 months after a Bankart-type anterior stabilization surgery. These authors[32] demonstrated repaired-limb concentric internal and external rotation strength of 104% in that of uninvolved limbs in older patients (60.8 years) treated for rotator cuff repair and acromioplasty. However, as previously discussed, our Open group's involved limbs were significantly weaker in internal rotation versus their uninvolved limbs at 90°/sec. Also, Arthroscopic group patients had a 12% involved-limb deficit in external rotation versus uninvolved limbs, although this was not significant. A likely confounding factor was that 67% of our Arthroscopic subjects had surgery on their nondominant shoulder. Thus, it may be possible that the external rotation peak torque deficits observed can be attributed to limb dominance rather than results of surgery. It should also be considered that three of our Arthroscopic patients had bilateral stabilizations performed. This factor decreased the involved/uninvolved limb comparisons that could be made in these subjects and reduced the sample size to five subjects. Because of low power, caution is warranted in generalizing these findings.

While the involved limb internal rotation strength was significantly less in Thermal patients compared to Arthroscopic patients at 90°/sec, the involved/uninvolved limb comparison is more appropriate to consider when determining an individual's development of postoperative strength. As such, Thermal patients demonstrated equivalent involved-limb strength compared to their uninvolved limbs. These findings agree with Ellenbecker and Mattalino,[15] who reported symmetrical external rotation strength and a 4% internal rotation strength deficit at 12 weeks after thermal capsulorrhaphy. Our findings suggest that full internal and external rotation strength was acquired and present in our Thermal patients at extended follow-up (27.5 months).

External Rotation/Internal Rotation strength ratios. Mayer et al.[55] suggested that muscular balance of the shoulder (agonist/antagonist ratio) is predictive of dynamic shoulder stability since static joint stabilizers do not effectively provide stability until end range of motion. Established norms for external/internal rotation strength ratios in healthy individuals are typically 0.67::1.0 when measured from a modified base testing position (30° abduction in the scapular plane),[9, 13] but can range from 0.53 to 0.83 in "normal" shoulders depending on testing velocity and position.[9, 98]

Altered external/internal rotation strength ratios have been demonstrated in the presence of glenohumeral instability and impingement.[13, 26, 70, 98] Due to selective strengthening of the internal rotators in overhead athletes, and subsequent alterations in the external/internal rotation strength ratio, some clinicians have begun performing posterior rotator cuff strengthening programs to prevent injury in the high-level overhead athletes.[13] Ellenbecker and Davies[13] recommended creating an external rotation bias toward a 0.75::1.0 external/internal rotation torque ratio in patients with instability. Increased posterior cuff strength may prevent excessive strain on the anterior joint capsule, a concept analogous to strengthening the hamstrings to complement the restraining function of the ACL. In general, our surgical subjects' mean involved limb external/internal rotation ratios (0.85::1.0) were higher than expected and were significantly higher at 90°/sec versus 270°/sec (0.88::1.0 versus 0.81::1.0). While no significant differences were found between surgical groups and controls collapsing across testing velocities, Arthroscopic patients demonstrated significantly better external/internal rotation ratios than did the Open capsulorrhaphy patients (0.74::1.0 versus 0.92::1.0) at 90°/sec. Both the Open and Thermal capsulorrhaphy patients' internal rotation strength deficits affected their external/internal rotation ratios (0.92:: 1.0 and 0.90::1.0, respectively), altering them considerably toward external rotation strength.

The internal rotation weaknesses observed in Open and Thermal capsulorrhaphy patients created an imbalance in the normal agonist/antagonist relationship of the rotator cuff, altering its dynamic stabilizing function at the glenohumeral joint. Weakness in the teres minor and subscapularis muscles may result in a deficiency of the inferior and caudal glide component provided by these muscles to center the humeral head within the glenoid against the superiorly directed vector of pull of the deltoid during progressive shoulder abduction.[44] This agonist/antagonist strength imbalance may partially explain the diminished objective function observed in the Open and Thermal group patients as reported on the ASES form (77/100 and 80/100, respectively) compared to Arthroscopic group patients (86/100) who exhibited a near-optimal (0.74::1.0) external/internal rotation strength ratio on average.

It is possible that our testing position, i.e., 90/90° abduction and elbow flexion in the scapular plane, influenced the strength ratios. Previously reported concentric strength data have demonstrated increases in external rotation strength and decreases in internal rotation strength with progressive glenohumeral abduction.[9] Because high ratios were observed across surgical groups and in healthy controls (0.81:: 1.0), this explanation seems plausible. We chose the 90°/90° position because it places the musculature in an optimal length-tension relationship and mimics the position of function in overhead activities.[13, 32] Modifying our position to 30° into the scapular plane enhanced bony congruity of the glenohumeral joint, reducing potential apprehension in our subjects during testing.

Objective and Subjective Ratings of Surgical Outcomes

A significant, positive correlation (r = 0.64) was observed between overall objective function (ASES clinical evaluation) and subjective patient scores (SRQ), indicating that improved shoulder function, stability, and diminished pain were directly related to functional ability and patient satisfaction at a mean follow-up of 32.1 months. This relationship was particularly strong in the Thermal group (r = .92). No significant differences in ASES or SRQ scores were observed among the three surgical groups.

Patients in the Open capsulorrhaphy group had lower overall ASES scores, reporting "satisfactory" results on average (77.1 of 100 possible points), while patients in the Arthroscopic and Thermal groups each reported "excellent" results (86.4 and 80.6, respectively). Warner[21] reported similar ASES scores (83.0) in 36 patients after arthroscopic Bankart/capsulorrhaphy repair at mean follow-up of 37 months. Potzl et al.[75] reported slightly lower ASES scores in 14 subjects treated with open (n =10) and arthroscopic (n = 4) Bankart/capsulorrhaphy repair (74.6 ± 22.9) at a mean follow-up of 5.9 years.

Multiple factors may have contributed to the decreased objective function outcome in our Open capsulorrhaphy patients. The prevalence of significant preoperative osseous lesions, e.g. Hill-Sachs and bony-Bankart lesions, was highest in Open capsulorrhaphy patients (29%) compared with Arthroscopic (21%) and Thermal capsulorrhaphy (6%) patients. These pathologic lesions may have diminished mechanical stability and increased level of pain, contributing to decreased postoperative function.[18, 57] Also, as previously stated, altered external/internal rotation strength ratios contributed to loss of dynamic functional stability in Open capsulorrhaphy patients.

Mean overall SRQ results demonstrated achievement of normal patient function and satisfaction on average in each group. The Arthroscopic and Open capsulorrhaphy groups had nearly identical mean scores on the SRQ, 85.1 and 85.2 out of 100 possible points, respectively. Patients in the Thermal group scored lower on average (80.5) but this difference was not significant. Lephart and colleagues[45] observed higher subjective function scores in 20 Thermal capsulorrhaphy patients (91.9/100 ± 5.4) at 12 months mean follow-up. However, data have shown diminished function[37, 54] and patient satisfaction as the follow-up period is extended in arthroscopic patients. This likely explains the discrepancy in our findings and the findings of Lephart and colleagues.[45] Extending the follow-up evaluation to a minimum of 2 years is generally required in clinical trials to allow for a more accurate assessment of surgical success.

We observed strong agreement between the Shoulder Evaluation form (ASES), which is a prevalent tool evaluating objective function for a variety of shoulder pathologies,[8, 16, 21, 68, 69] and the recently-developed Shoulder Rating Questionnaire (SRQ), which assesses patient-based outcomes after surgery.[21, 45, 51] Related shoulder scoring systems such as the UCLA scale, the modified-Rowe scale, the Walch-Duplay system, and the Constant-Murley system have each been utilized to report objective and subjective clinical results. However, a widely-accepted shoulder scoring system is not currently available. This is likely due to limited psychometric data evaluating validity, correlation, and interrater reliability among these systems.[80] Further, these scoring systems often yield varying results when evaluating shoulder outcomes in similar patient populations.[80] Our results suggest that the ASES and SRQ clinical tools are complimentary to each other, providing the clinician with a clinical assessment of objective functional capacity as well as patient satisfaction.

Strengths and Limitations

Our mean follow-up period of nearly three years (32 months) expands the current body of knowledge and improves the level of confidence in the validity of these results. Also, we measured passive external range of motion individually prior to assessing proprioception, allowing for equal amounts of tension to be achieved in each subject's shoulder. We agree with Janwantanakul et al.[38] that future studies should consider an individual's joint mobility when measuring joint position sense.

One of the limitations of this study was that there was no standardized period of rehabilitation or exercise protocol given to all our subjects. In addition, the potential for selection bias existed as patients were not randomly assigned to surgical groups.

Conclusions. Our results indicate that joint repositioning accuracy for external rotation movements is similar between the postsurgical and contralateral normal shoulders in patients who have had open, arthroscopic and thermal repair of recurrent anterior shoulder instability. Patients who underwent Open repairs exhibited better proprioception than arthroscopic, thermal, and uninjured controls. This effect may be the result of a heightened focus on optimal anteroinferior stabilization with the traditional open capsular shift procedure. However, the postoperative internal rotation strength deficits in open-repaired patients present a significant concern and should be considered when determining treatment. Finally, clinician-based evaluation may be useful in predicting postoperative patient satisfaction as objective function and patient satisfaction were significantly related. Controlled, randomized studies are still needed to evaluate long-term outcomes in these capsulorrhaphy procedures.

Clinical Relevance. Evaluation of both objective and subjective outcomes is essential to determine the ideal surgical technique for the individual patient. Ours is the first study to date comparing these outcomes among open, thermal, and arthroscopic glenohumeral capsulorrhaphy patients. Our findings suggest that open AGHI stabilization procedures optimally restored glenohumeral joint proprioception to equal that of the uninjured limb. Newer arthroscopic anchoring procedures are preferred over open repair for the athletic patient who requires functional postoperative range of motion and maximal internal rotation strength.

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CHAPTER 3

Patient-based outcomes predict operative success in the treatment of glenohumeral instability: A comparison of open, arthroscopic, and thermal capsulorrhaphy techniques

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Abstract

Background: Open, thermal, and arthroscopic glenohumeral capsulorrhaphy procedures have each been advocated to address chronic anterior glenohumeral instability. The purpose of this study was to compare specific objective and subjective shoulder outcomes after these common procedures, and to determine the extent to which these parameters of shoulder function are predictive of surgical success as evidenced by a patient's postoperative satisfaction and functional ability.

Methods: We evaluated fifty-one shoulders in forty-seven patients (32 men, 15 women) who underwent open, arthroscopic, or thermal capsulorrhaphy for repair of chronic, recurrent shoulder instability. Anterior instability was the indication for surgery in eighty-three percent of the patients. Patients were evaluated at an average of thirty-two months after surgery (range, 6 to 96 months). Outcome measures included the American Shoulder and Elbow Surgeons (ASES) shoulder evaluation form score, the Shoulder Rating Questionnaire (SRQ) score, level of pain, frequency of recurrent instability, return to activity, rotator cuff strength profile, and composite joint position sense. Results were analyzed by surgical group and diagnosed instability (anterior, subtle, or multidirectional).

Results: Successful outcomes were achieved in forty shoulders (78 %), while unsatisfactory clinical results were observed in eleven (22 %). No postoperative dislocations occurred in any surgical group. Overall ASES scores were satisfactory (80.55/100 ± 12.94), and SRQ scores (83.90/100 ± 11.63) indicated normal postoperative function and satisfaction in each group. Success rates, i.e., no recurrent episodes of

postoperative shoulder subluxation or dislocation and/or ASES overall scores > 70/100, were 86 % with arthroscopic capsulorrhaphy, 76 % with the open technique, and 75 % in thermal capsulorrhaphy patients. Arthroscopic capsulolabral repair resulted in a lower risk of recurrent instability and higher ASES clinical outcome scores (86.4 ± 8.5) compared to the thermal (80.6 ± 15.1) and open capsulorrhaphy groups (77.1 ± 13.1). While thermal patients had the least restriction in external rotation motion (2.2°), three patients (20 %) required revision surgery, and three rated their shoulder as "poor" postoperatively. Patients' postoperative level of pain and ASES clinical score were significant predictors ($R = .81, p < .001$) of their level of satisfaction and functional ability reported on the Shoulder Rating Questionnaire (SRQ). In addition, patients' postoperative SRQ scores were a significant predictor ($R = .64, p < .001$) of their objective ASES score. Both the ASES and SRQ clinical results were significantly lower in patients with multidirectional instability versus those with traumatic anterior instability ($p = 0.03$), and in patients with postoperative instability (subluxation) versus those without ($p < .001$).

Conclusions: Arthroscopic capsulolabral repair resulted in the lowest recurrent instability rate and highest ASES clinical outcome scores. We observed a higher failure rate, more revision surgeries, and lower patient satisfaction with the thermal capsulorrhaphy technique. These findings support the growing number of studies that have reported problems associated with thermal repair, particularly in patients with multidirectional instability. Patient-based outcomes are useful in predicting operative success as measured by clinician-based evaluation. Further, ASES outcomes are useful

in predicting patient satisfaction and functional ability in patients repaired with open, thermal and arthroscopic capsulorrhaphy.

Clinical Relevance: This is the first direct comparison of patient-based, subjective and objective clinical outcomes across three surgical procedures for glenohumeral instability. While the high rate of success observed among the arthroscopic capsulorrhaphy patients was encouraging, a larger patient population must be studied prior to making conclusions regarding the efficacy of this treatment. Until better, long-term follow-up evidence becomes available, the continued use of thermal capsulorrhaphy in the treatment of glenohumeral instability was not supported by our findings.

Keywords: patient-based outcomes, shoulder instability; arthroscopic capsulorrhaphy; open capsulorrhaphy, thermal capsulorrhaphy.

INTRODUCTION

The glenohumeral joint is the most frequently dislocated major joint in the body, with 80-95% of traumatic cases occurring anteriorly.[64] Anterior glenohumeral instability is uniquely problematic in the young patient with a first-time dislocation, and in athletes participating in high-contact or collision sports.[2, 50, 58] Recurrent instability has been reported as high as 80% to 94% in these patients.[25, 39, 58]

Surgical stabilization aims to restore glenohumeral joint stability and return patients to preoperative levels of function. Multiple clinical measures of objective and subjective function indicate the extent to which this is achieved. These outcomes, which ostensibly indicate surgical success, may be inadequate predictors of actual patient status. This is evidenced by the inconsistency with which common shoulder scoring systems report objective and subjective clinical results.[34, 40, 55] Romeo et al.[55] noted disparate results while measuring outcomes in the same patient population with surgically repaired instability using four common clinician-based and patient-based scoring systems.

Traumatic anterior dislocation often results in anterior capsulolabral pathology (Bankart lesion) as well as altered neuromuscular control of the shoulder.[15, 29, 44, 62] While some patients with unresolved mechanical instability are surprisingly functional during activity or work, other patients may continue to lack functional capacity to perform at a high level, even after surgical resolution of capsulolabral pathology. Further, a patient with excellent clinical stability may experience pain levels rendering an unsatisfactory surgical outcome from their perspective. The correlation between clinician-based and patient-based outcomes is often unclear. Further, while clinician-based assessments are pervasive in the literature, patient-based outcomes assessment has been traditionally lacking.[35]

Open, thermal, and arthroscopic capsulorrhaphy procedures have each been advocated to address recurrent glenohumeral instability.[2, 11, 38, 43, 46, 49, 56, 57] To date, no "gold standard" surgical technique for the management of this condition has been identified. No single study has previously compared subjective and objective outcomes after these three common surgical procedures. Therefore, it is necessary to assess not only postoperative joint stability, muscular strength, rate of recurrence, and joint proprioception, but also qualitative patient-based outcomes including patient satisfaction and perceived ability to return to sport/activity.[58] These subjective parameters provide additional insight regarding the level of patient function rather than solely focusing on the anatomic success of surgical repair.

The purpose of this study was to compare specific shoulder objective and subjective outcomes after open, arthroscopic, and thermal capsulorrhaphy for recurrent anterior glenohumeral instability, and to identify parameters that were most predictive of surgical success, patient satisfaction, and functional ability.

MATERIALS AND METHODS

We evaluated fifty-one shoulders in forty-seven patients (thirty-two men, fifteen women; mean age, 23.7 ± 6.8 years) who underwent surgical repair of chronic, recurrent shoulder instability. Indications for surgery were traumatic, anterior instability in forty-two patients (83 %), and multidirectional instability (MDI) in nine patients (17 %). We recruited our subjects through direct contacts with twelve orthopedic surgeons in Oregon and California; each patient's treating surgeon referred him or her for participation in this study. Our Institutional Review Board for the Protection of Human Subjects approved the study protocol prior to data collection.

Study Groups

In this retrospective study, patients were classified into one of three groups based on the type of surgery they received: *Open Capsulorrhaphy (OC)*, sixteen men and four women (twenty-one shoulders) had an open capsular shift with or without a Bankart repair; *Arthroscopic Capsulorrhaphy (AC)*, nine men and four women (fourteen shoulders) had arthroscopic capsular plication with or without a Bankart repair; and *Arthroscopic Thermal Capsulorrhaphy (TC)*, seven women and seven men (sixteen shoulders) had arthroscopic thermal capsulorrhaphy either as an isolated procedure or an adjunct to labral repair.

Entry criteria included: (a) no history of concomitant glenohumeral impingement or rotator cuff pathology, (b) full discharge from postoperative rehabilitation, and (c) physician clearance for return to activity and/or employment. We obtained the operative reports for each patient, including the postoperative diagnosis, to ensure that no additional shoulder pathology existed. Patients who underwent concomitant repairs of superior labral anterior-posterior (SLAP), Hill-Sachs, or osseous Bankart lesions were retained in the study. One patient who had an associated rotator cuff repair and subacromial decompression was excluded from the analysis.

Patients were retrospectively tested at an average of 32.1 ± 24.8 months following surgery (range, 6 to 96 months). Concomitant shoulder pathology at time of surgery included thirty-six patients with Bankart lesions (72%), eight with SLAP lesions (16%), seven with Hill-Sachs lesions (14%), and two with osseous Bankart lesions (4%).

We selected seven factors to evaluate objective and subjective shoulder function in the repaired limbs of patients. These factors included the: (a) American Shoulder and Elbow Surgeons shoulder evaluation form, (b) Shoulder Rating Questionnaire, (c) level of postoperative pain, (d) joint position sense, (e) concentric internal rotation peak torque, (f) concentric external rotation peak torque, and (g) external rotation/internal rotation peak torque ratio.

Outcomes Assessment

Objective assessment. We evaluated postoperative objective shoulder function using the standardized assessment form of the Society of American Shoulder and Elbow Surgeons (ASES).[54] The ASES measures six patient outcomes and assigns point values to five of these, e.g., pain, motion, strength, stability, and function. Various methods for scoring the ASES form have been proposed.[54, 55] We utilized the scoring guidelines provided by the ASES Society[54], scoring only the pain and function outcomes as follows: [(10-Visual analog scale pain score) x 5] + (5/3 x Function score) = total score/100. ASES clinical scores of 85-100/100 indicate *excellent* clinical results, scores of 70-85/100 indicate *satisfactory* clinical results, and scores < 70/100 indicate *unsatisfactory* clinical results.[54]

Subjective assessment. Postoperative functional status and patient satisfaction were evaluated using the Shoulder Rating Questionnaire (SRQ).[34] The SRQ has been demonstrated as a valid, reliable, and responsive instrument to clinical change.[34] The SRQ is comprised of twenty-one questions that measure six domains of patient function, five of which are scored. These domains include global assessment, level of postoperative pain, ability to perform daily activities, recreational/athletic activities, and work. There is one open-ended question on the SRQ that addresses patient satisfaction by means of a response to the query: "*After having surgery, my shoulder is* ____________________"; the answer to this question was not assigned a point value.

Glenohumeral Joint Position Sense. We assessed shoulder joint position sense with two passive reproduction of passive positioning (PRPP) tasks using an isokinetic dynamometer (Biodex System 3 Pro™, Biodex Medical, Inc., Shirley, NY). A customized shoulder-positioning device secured subject's limbs to the dynamometer. (Figure 1) Two target positions were individually established after determining each subject's maximum passive external rotation (MER) range of motion and calculating 60% and 90% of that value. These target angles corresponded to the mid-range (60% ER_{max}) and end-range (90% ER_{max}) of the subject's available external rotation ROM; two previous studies have employed a similar protocol.[27, 60] We utilized the continuous passive motion (CPM) mode of the dynamometer to perform the PRPP tests. The shoulder under investigation was passively rotated by the dynamometer at 10°/sec from neutral rotation into external rotation to one of two target positions, 60% ER_{max} or 90% ER_{max}. The shoulder was held at the target position for 5 seconds, and returned to the starting position. The blindfolded subjects were instructed to indicate when they believed the target angle had been reached by pressing the dynamometer's hand-held cutoff switch to disengage the motor powering the CPM mode. The device's internal goniometer provided us with the joint position to the nearest whole degree. We calculated the accuracy with which the subject reproduced the target position as the absolute difference between the target angle and the position identified by the subject. The order of testing was counterbalanced between limbs and target positions.

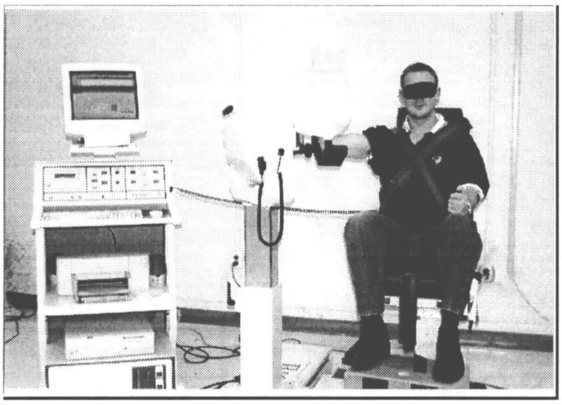

Figure 1. The Biodex MultiJoint System 3 Isokinetic Dynamometer was utilized for joint position sense and isokinetic strength data collection (JPS testing shown).

Shoulder Strength Measures. Isokinetic evaluation of concentric internal rotation and external rotation peak torque, and external rotation/internal rotation peak torque ratios was conducted with the same dynamometer used for PRPP testing (Biodex System 3 Pro). Peak torque values were obtained from 5 maximal repetitions at testing velocities of 90°/sec, 180°/sec, and 270°/sec. A composite shoulder strength score was calculated for each patient as the mean peak torque across all three testing velocities. This composite value was entered into the data analysis. Peak torque (Nm) was normalized to body weight (kg) in order to allow for meaningful comparisons among our heterogeneous patient population.[7]

Prior to testing, all patients performed a 10-minute warm up session on an upper-body stationary ergometer at a submaximal level, and then completed three submaximal internal and external rotation practice trials on the dynamometer at each testing velocity. Gravity correction software was employed as gravity was a factor at our 90° abduction/90° elbow flexion testing position. We evaluated both the untreated and repaired shoulders using standardized patient and dynamometer positioning, verbal commands, and testing protocol.

Statistical Analysis

All data were analyzed using SPSS statistical software (version 11.0, SPSS Inc., Chicago, IL). Patient demographic data were descriptively evaluated via measures of central tendency and cross-tabulation by surgical group and type of instability (traumatic/anterior, subtle, MDI). Interrelationships between objective and subjective factors were evaluated using Pearson product-moment correlation analysis ($p <.05$). Two stepwise multiple regression analyses were performed in effort to gauge how well the various objective and subjective measures were able to predict the total ASES and SRQ scores ($p < .05$). In addition, SRQ and ASES outcomes were compared among surgical groups using one-way ANOVA's ($p <.05$).

RESULTS

We evaluated the results of open, arthroscopic, and thermal glenohumeral capsulorrhaphy in fifty-one shoulders of forty-four patients at an average follow-up of 32.1 months. Twenty-seven subjects (53 %) had surgery on their dominant limb (twenty-four right shoulders, three left shoulders). Nine patients (18 %) participated in collegiate athletics at the time of follow-up. The clinical data of three patients' were excluded from the analysis as one patient had not been discharged from rehabilitation at commencement of the study and two patients did not complete the ASES and SRQ forms.

Patient demographics are summarized in Table 1. Objective (ASES) and subjective (SRQ) outcome scores and subscales are presented in Table 2 through Table 6. Overall, forty shoulders (78 %) attained successful outcomes, with eighteen (35 %) “excellent” and twenty-two (43 %) “satisfactory” results. Unsatisfactory outcomes were observed in eleven (22 %) patients, reflecting recurrent episodes of postoperative shoulder subluxation and/or ASES overall scores less than 70/100. No postoperative dislocations occurred in any surgical group. Also, there were no significant differences in SRQ scores ($p = 0.49$, $1 - \beta = 0.17$) or ASES scores ($p = 0.12$, $1 - \beta = 0.44$) among the surgical groups. The overall ASES mean score (averaged across surgical groups) was categorized as “satisfactory” (80.6/100 ± 12.9 points). Patient satisfaction and function, as quantified with the SRQ form, were 83.9/100 ± 11.6 points on average, suggesting normal postoperative function and satisfaction in each group.

TABLE 1

Summary of patient demographic information (N = 51).

VARIABLE	GROUP Open	 Arthroscopic	 Thermal
Number of patients	21	14	16
Age (mean ± SD)	28.0 ± 9.6	20.2 ± 1.2	21.0 ± 2.1
Months postoperative (mean ± SD)	40.8 ± 29.9	24.5 ± 19.9	27.5 ± 15.7
Males	17	10	7
Females	4	4	9
Anterior instability	19 (91%)	14 (100%)	9 (56%)
Multidirectional instability	2 (19%)	0	7 (44%)
Bankart lesion	14 (67%)	12 (86%)	7 (44%)
Preoperative dislocation	19 (91%)	11 (79%)	11 (69%)
Patients with > 10 episodes	5 (24%)	2 (14%)	0
Preoperative subluxation	16 (76%)	13 (93%)	10 (71%)
Patients with > 10 episodes	7 (33%)	5 (36%)	3 (19%)
No postoperative instability	16 (76%)	14 (86%)	12 (75%)
Postoperative dislocation	0	0	0
Postoperative subluxation	5 (24%)	2 (14%)	4 (25%)
Subjects requiring revision procedure	0	1* (7%)	3* (19%)
Mean loss of ER compared to opposite	11.9°	4.9°	3.8°
Able to return to sport activity without significant limitations	68%	65%	57%
Able to return to work without significant limitations	95%	100%	93%

*AC: 1 revision, suture anchor failure; TC: 3 revisions, each had capsular attenuation.

TABLE 2
ASES Subscale Outcomes

	GROUP		
Subscale:	**Open**	**Arthroscopic**	**Thermal**
Pain:*	2.7/10	2.2/10	2.9/10
Motion: (difference in injured-uninjured)†			
ER at 0° ABD	-10.4°	-5.4°	-5.5°
ER at 90° ABD	-13.4°	-4.5°	-2.2°
IR (mean vertebra reached)	T6	T7	T6
Stability: anterior (mean)‡	3.7/5	4.1/5	4.1/5
Function/ADL's:[§]	24.6/30	25.8/30	24.9/30
Patient Response:**			
"Much better"	60%	36%	50%
"Better"	25%	50%	25%
"Same"	5%	14%	12.5%
"Worse"	10%	0%	12.5%

* Patient-reported scale: "0" = no pain and "10" = complete disability.

† Negative numbers indicate range of motion of injured shoulder less than the uninjured.

‡ 5=Normal, 4=Apprehension, 3=Rare subluxation, 2=Recurrent subluxation, 1=Recurrent dislocation.

§ Patient function and ability to perform activities of daily living.

**Response when asked: *"After having surgery, my shoulder is ________."*

TABLE 3.
Evaluation of ASES[a] Clinical Results by Surgical Procedure.

	Open	**Arthroscopic**	**Thermal**
	n (%)	n (%)	n (%)
ASES Clinical Results:			
Excellent*	7 (33%)	6 (43%)	5 (31%)
Satisfactory†	9 (43%)	8 (57%)	7 (44%)
Unsatisfactory‡	5 (24%)	0	4 (25%)
Overall ASES Score[§]:	77.1 ± 13.1[§]	86.4 ± 8.5	80.6 ± 15.1

a American Shoulder and Elbow Surgeons' Shoulder evaluation form.

* *Excellent* = 85-100/100, satisfaction score >9/10, return to activity without difficulty, and no clinical instability.

† *Satisfactory* = 70-85/100, satisfaction score > 5/10, return to activity with some difficulty, and no clinical instability.

‡ *Unsatisfactory* = <70/100, satisfaction score <5/10, cannot return to work/sport, instability. (Scoring Adapted from *D'Alessandro et al., 2004*)

[§] No significant group differences were observed in overall ASES scores (*P* = .12)

Surgical Group Results

Open Capsulorrhaphy (OC) Group. Among the twenty-one shoulders (seventeen male, four female) treated with open repair, nineteen (91 %) had traumatic, anterior instability, and two were classified with multidirectional instability (MDI) based on global capsular laxity noted in the operative report (Table 1). Bankart lesions were common (67 %) in the OC group, and five shoulders (23 %) experienced more than ten dislocations prior to surgery. OC patients had lower mean ASES clinical outcome scores (77.1 ± 13.1) than AC and TC groups, although not significant ($p = .12$). These patients were evaluated at longest mean follow up period (40.8 months). Clinical outcomes were excellent or satisfactory in sixteen (76 %) (Table 3).

Five OC patients (23 %) experienced episodes of subluxation after surgery; both MDI shoulders were included in this subgroup. On the contrary, OC patients had the most favorable SRQ functional outcome scores (85.2 ± 12.6) (Table 2). Their mean global assessment of shoulder function was also highest (8.0/10), and 95 % reported overall postoperative satisfaction as "good", "very good", or "excellent" (Table 5).

TABLE 4

Correlations of ASES and SRQ Outcomes in Surgical Groups.

	ASES Score					
	Open		**Arthroscopic**		**Thermal**	
	r	*p*	*r*	*p*	*r*	*p*
SRQ Score	.43	≤ .05	.60	.038	.92	< .001

TABLE 5

Shoulder Rating Questionnaire (SRQ) Outcomes

	GROUP		
DOMAIN:	**Open (n=19)**	**Arthroscopic (n=14)**	**Thermal (n=14)**
Overall Score: (100 possible)	**85.2 ± 12.6**	**85.1 ± 13.4**	**80.5 ± 13.3**
Global Assessment*	8.0/10	7.2/10	7.5/10
Pain:†	34.4/40	34.9/40	31.9/40
Daily Activities Limitations:‡			
None or Mild	19 (100%)	12 (86%)	10 (72%)
Moderate or Severe	0	2 (14%)	4 (28%)
Recreation/Athletic Limitations:			
None or Mild	13 (68%)	9 (65%)	8 (57%)
Moderate or Severe	6 (32%)	5 (35%)	6 (43%)
Work Limitations:			
None or Mild	18 (95%)	14 (100%)	13 (93%)
Moderate or Severe	1 (5%)	0	1 (7%)
Patient Satisfaction:§			
Excellent	7 (32%)	2 (14%)	4 (27%)
Very good	8 (36%)	6 (43%)	4 (27%)
Good	6 (27%)	3 (21%)	3 (20%)
Fair	1 (5%)	3 (21%)	1 (7%)
Poor	0	0	3 (20%)

* Patient's overall rating of shoulder function on a 10 cm visual analog scale (0=very poor and 10=very well)

† Patient reported severity and frequency of pain. (8= worst score, 40 = best)

‡ Reported ability to use shoulder during activities of daily living (ADL's), during recreational and athletic activities, and at work. Options included: No limitation, Mild limitation, Moderate limitation, Severe Limitation, and Unable.

§ Patient response to: "*Rate your overall degree of satisfaction with your shoulder*".

Arthroscopic Capsulorrhaphy (AC) Group. Of fourteen shoulders (71% males, 29% females) managed with arthroscopic repair, all had traumatic, anterior instability and twelve (86 %) underwent concomitant Bankart repair. While twelve patients (86%) had no postoperative instability, two experienced subluxation. Both episodes occurred in throwing athletes: a recreational softball player and a collegiate baseball player. The AC patients had the most favorable mean ASES clinical outcome scores (86.4 ± 8.5), with excellent or satisfactory results in 100% at mean follow-up of 24.5 months (Table 3). Eleven of fourteen patients (79%) reported "good", "very good", or "excellent" overall satisfaction with their repaired shoulders.

Thermal Capsulorrhaphy (TC) Group: The TC group (sixteen shoulders) was distinct as the majority of patients were women (57%), and seven shoulders (44%) had documented multidirectional instability. The mean ASES clinical outcome score was 80.6 ± 15.1, with "excellent" or "satisfactory" results in twelve (75%) patients. Thermal patients had the lowest rate of traumatic preoperative dislocation (69%), but the highest rate of postoperative recurrent instability (25%). While eleven (74%) TC patients reported "good", "very good", or "excellent" overall satisfaction with their repaired shoulders on the SRQ, one reported "fair", and three (19%) "poor" levels of satisfaction at an average of 27.5 months postsurgery.

Return to Athletics, Recreational Activity, and Work (SRQ Subscales)

Open Capsulorrhaphy Group. The OC patients were the most successful as a group, as all fourteen (100%) were able to return to daily activities without significant limitations (Table 5). The sole collegiate athlete in this group was a rower who returned to sport with moderate limitations. Four individuals were unable to return to their previous level of recreational activity; these activities included football, basketball, throwing a baseball, and weightlifting.

Arthroscopic Capsulorrhaphy Group. Three collegiate athletes and eleven active individuals comprised the AC group. In the total, twelve of fourteen patients (86%) accomplished daily activities with little or no limitation; all patients were able to return to work without significant limitations. Each of the collegiate athletes was able to return to his/her sport; one returned to basketball with no limitations, and two to volleyball and baseball with moderate limitations. However, five patients (35%) had moderate or severe limitations with recreational activities/athletics. One patient was unable to return to recreational baseball and one unable to throw a football.

Thermal Capsulorrhaphy (TC) Group. Thermal patients included five collegiate athletes and nine active individuals. This group experienced higher rates of moderate to severe limitations with regard to the ability to return to daily activities (28%) and recreational or athletic activities (43%). Three of the five collegiate athletes were able to return to baseball, volleyball and softball with mild or no limitations, while two athletes (one volleyball player, one softball player) had moderate or severe limitations and persistent pain with overhead activity.

Revision Surgery

Four patients required revision surgery secondary to recurrent postoperative subluxation. One AC patient experienced suture anchor failure at fourteen months, and three TC patients had significant capsular attenuation at an average of twenty-eight months follow-up. Of interest was a collegiate softball pitcher who reported excellent satisfaction (SRQ score = 94.4/100) and clinical results (ASES score = 88/100) at three years follow up after thermal repair. However, on reassessment seven months later, she complained of recurrent pain and experienced more than twenty episodes of subluxation with pitching. Resulting SRQ and ASES scores dropped dramatically (SRQ = 45/100, ASES = 54/100). This patient underwent arthroscopic capsular shift during the off-season.

Correlation of Objective and Subjective Outcomes

Ten significant correlations were demonstrated among the shoulder outcome variables ($p < .05$) (Table 6). The concentric strength variables were most highly interrelated ($r = .88$). A significant, positive correlation existed between overall ASES and SRQ outcome scores ($r_{(47)}$, = .63; $p < .001$); the strongest relationship occurred in TC patients ($r_{(15)} = .92$; $p < .001$). Interestingly, patients' levels of postoperative pain were strongly related to their reported global satisfaction with surgery ($r_{(47)} = .76$; $p<.001$). Also, the ER/IR strength ratio and SRQ scores had a significant, negative correlation ($r_{(47)} = -.30$; $p < .05$). Patients with imbalance of the glenohumeral rotators (weak internal rotators resulting in higher ER/IR ratios) had lower SRQ satisfaction scores on average. Joint position sense (JPS) and length of follow-up period (number of months) were not significantly related to any of the outcome variables ($p = .09$ to .55).

Multiple Regression Analysis

Two stepwise multiple regression analyses were performed with outcomes chosen as independent variables in based on the frequency with which these outcomes are employed in the clinical setting to indicate shoulder function.[8, 9, 22, 23, 34, 49, 50] A multiple linear regression was calculated to predict patients' SRQ clinical score from their strength profile, i.e., external and internal rotation peak torque and external/internal rotation peak torque ratio, composite joint position sense, number of months follow-up period, and level of pain at time of testing. In addition, a multiple linear regression analysis was calculated to predict patients' ASES scores from patient's strength profile, SRQ clinical score and length of follow-up period (in months).

Patients' postoperative level of pain and ASES scores were found to be significant predictors of their SRQ clinical scores ($F_{(2,39)} = 53.3, p < .003$; $R = .81, R^2 = .65$). Patients' predicted SRQ clinical score was equal to 26.19-1.02 (PAIN SCORE) + .29 (ASES SCORE). The shoulder strength profile ($p = .13$ to .23) joint position sense ($p = .42$), and length of follow-up period ($p = .38$) variables were not significant predictors of overall objective function (ASES) or patient satisfaction (SRQ) clinical outcomes.

TABLE 6

Pearson product-moment intercorrelation matrix (significance levels below) for repaired shoulder variables.

	JPS	Months Post	Global Satisfac	Pain score	ASES	SRQ	IR Peak Torque	IR/ER Ratio	ER Peak Torque
Joint Position Sen		-.13	.00	.19	.21	.20	.18	-.25	.09
	.	(.39)	(.98)	(.22)	(.16)	(.20)	(.22)	(.10)	(.55)
Months Post	-.13		.00	.20	-.13	-.06	.00	-.16	-.09
	(.40)	.	(.99)	(.19)	(.36)	(.69)	(.99)	(.29)	(.56)
Global Satisfaction	.005	.00		.76**	.37*	.68**	.08	-.23	-.03
	(.98)	(.99)	.	(.000)	(.01)	(.000)	(.61)	(.14)	(.86)
Pain score	.19	.20	.76**		.51**	.75**	.17	-.33*	.01
	(.22)	(.19)	(.000)	.	(.000)	(.000)	(.28)	(.03)	(.96)
ASES (total score)	.21	-.13	.37*	.51**		.63**	.19	-.22	.08
	(.16)	(.36)	(.011)	(.000)	.	(.000)	(.21)	(.13)	(.58)
SRQ (total score)	.19	-.06	.68**	.75**	.63**		.11	-.30*	-.05
	(.19)	(.69)	(.000)	(.000)	(.000)	.	(.48)	(.047)	(.74)
IR Peak Torque	.18	.00	.08	.17	.19	.11		-.52**	.88**
	(.22)	(.99)	(.61)	(.28)	(.21)	(.48)	.	(.000)	(.00)
IR/ER ratio	-.25	-.16	-.23	-.33*	-.22	-.30*	-.52**		-.09
	(.09)	(.29)	(.14)	(.03)	(.13)	(.047)	(.000)	.	(.57)
ER Peak Torque	.09	-.09	-.03	.01	.08	-.05	.88**	-.09	
	(.55)	(.56)	(.86)	(.96)	(.58)	(.74)	(.000)	(.57)	.

**Significant at the 0.001 level (2-tailed).

* Significant at the 0.05 level (2-tailed).

[a] Mean peak torque at 90°/sec, 180°/sec, and 270°/sec. Measured at 90°ABD starting from neutral rotation.

[b] Agonist/Antagonist strength ratio (external/internal rotators).

[c] Joint position sense. Measured as reproduction of passive positioning of 2 target positions (60% and 90% of maximum external rotation range of motion).

DISCUSSION

The optimal stabilization procedure for the management of glenohumeral instability is currently being debated. While the success of early arthroscopic procedures has varied widely (failure rates ranging from 5 % to 60 %) with failure rates significantly higher than open repair,[2,14,26,46] recent advances using suture anchors and capsular plication have dramatically improved success rates.[5,14] Benefits of arthroscopic stabilization include decreased surgical morbidity and postoperative pain, improved ability to return to overhead sports, and reduced rehabilitation time.[20,41,49] However, concern exists that recurrent glenohumeral instability continues to be higher in arthroscopic versus open capsulorrhaphy (1 % to 10 % failure rates).[5,14,26] While open stabilization remains the preferred treatment for limiting recurrent instability,[4,5,14,25,31,37,47,50,52,56,57] disadvantages include the loss of motion due to capsular over-constraint, diminished capacity to return to high-level overhead activity, and impaired internal rotation strength due to resection of the subscapularis.[3,31;41,52]

The recent use of thermal capsulorrhaphy has had strong appeal among orthopedic surgeons because of its success in enhancing shoulder stability by reducing capsular volume.[12,18,46,61] However, the capsular shrinkage occurs with concomitant collagen denaturation, which has been shown in animal models to cause deleterious effects on the histological and biomechanical properties of collagenous tissues.[24,45,48,59] While insufficient data exists on the long-term effects of thermal energy applied to the human glenohumeral joint, the implementation of thermal capsulorrhaphy has outpaced controlled trials necessary to determine its efficacy.[1,4,6,32] Due to recent clinical reports that have identified frequent and serious complications following thermal repair,[18,32] the procedure is currently being used sparingly. Many surgeons now incorporate thermal capsulorrhaphy only as an adjunct procedure for addressing capsular laxity, after a Bankart lesion has been effectively stabilized.[1, 30, 31, 51, 63] Its use in patients with MDI has resulted in particularly high failure rates and diminished clinical outcomes.[6]

The primary objective of this study was to compare the efficacy of thermal capsulorrhaphy with current open and arthroscopic stabilization procedures in the treatment of glenohumeral instability. Our purpose was to quantify the various surgical outcomes and to clarify the indications of each stabilization procedure for restoring shoulder function; predominantly in patients with traumatic, anterior instability. To our knowledge, this is the first direct comparison of these procedures.

Surgical Group Outcomes

Arthroscopic capsulolabral repair resulted in a lower risk of recurrent instability and higher clinical outcome scores (ASES) compared to thermal and open procedures. While each surgical procedure was effective in preventing recurrent dislocation, we observed a higher rate of postoperative subluxation in patients treated with thermal and open capsulorrhaphy (25% and 23%, respectively) versus arthroscopic repair (14%). There are several possible explanations for these findings:

Thermal Capsulorrhaphy. The denaturation of collagen tissue associated with thermal capsular shrinkage has, in certain cases, resulted in capsular ablation, chondrolysis[32, 51] and arthrofibrosis.[18] These complications appear to contribute to higher failure rates.[6, 10] The type of preoperative instability in each surgical group, e.g., traumatic anterior versus multidirectional, likely influenced the postoperative outcomes. While patients with traumatic, anterior instability had good clinical results with each of the surgical procedures, patients in the MDI subgroup reported the poorest surgical results. Of particular interest were four patients who failed thermal treatment, all of whom had MDI. The higher incidence of MDI (44%) in our thermal patients appears to have directly influenced recurrence as well as ASES and SRQ clinical outcomes. For instance, by removing the nine MDI patients from the analysis (seven TC, two OC) and comparing only patients with anterior instability, ASES scores improved from 80.6 to 83.9 in TC patients, and from 77.1 to 78.5 in OC patients. Likewise, SRQ outcomes improved from 80.5 to 83.6 in TC patients and 85.2 to 85.4 in OC patients. This adjusted analysis resulted in outcomes in thermal patients approaching those observed in arthroscopic patients (ASES = 86.4, SRQ = 85.1). The point difference signifying clinically meaningful change (minimal clinical important difference) for the ASES has been determined to be 6.4 ASES points.[40] Thus, no clinically significant differences were evident among surgical groups in ASES scores. We are unaware of published data evaluating the SRQ form's responsiveness to clinical change.

Our results support those in previous studies[6, 42] who cited the limited effectiveness of thermal repair in patients with multidirectional instability. D'Alessandro[6] documented particularly high unsatisfactory outcomes (50% failure rate) in a subgroup of twenty-eight female athletes with MDI. Miniaci[42] further clarified that patients with a predominantly anteroinferior component of MDI fared much better (20% failure) than those with a voluntary, posterior component of MDI (100% failure). On the contrary, Levy et al.[33] proposed that thermal capsulorrhaphy is a viable alternative for open capsular shift in this difficult subgroup of patients with MDI. These authors determined that thermal treatment using radiofrequency energy resulted in lower failure (24%) than with laser-assisted capsulorrhaphy (36%). Finally, Fitzgerald and colleagues[13] successfully returned 76% of their active military patients with MDI to full activity after thermal repair. However, Fanton[12] and Fitzgerald et al.[13] both concluded that while its potential is evolving, the long-term beneficial effects of thermal capsulorrhaphy in the treatment of MDI remain to be determined.

Open Capsulorrhaphy. The rate of recurrent subluxation in our open-repaired patients was higher than previous reports.[14, 19, 20, 26, 31] Recurrence was likely affected by a high incidence of preoperative instability (five OC patients had more than ten dislocations and seven had more than ten subluxations) (Table 1). The prevalence of significant preoperative bony lesions may also have contributed;[14, 41] although this is debated by others.[49] Indeed, the highest rate of Hill-Sachs and/or osseous Bankart lesions (29%) was noted in OC patients. Additionally, OC patients were evaluated at longer follow-up than AC and TC patients (40.8 months versus 24.5 and 27.5 months, respectively). Data have supported diminished function and patient satisfaction outcomes as postoperative follow-up is extended.[26, 36] All OC patients experienced postoperative subluxation via traumatic activity, e.g., snowboarding, football, wrestling, bench-pressing, and rowing.

In contrast, open capsulorrhaphy patients reported the highest overall satisfaction with their repaired shoulders (Table 5) and were most able to return to daily and recreational activities. Mancuso[35] studied patients' preoperative expectations for shoulder surgery, observing that the most frequently cited expectations were "the ability to return to sports", to "stop dislocation", and to get their shoulder "back to the way it was before injury". Stabilization with open capsulorrhaphy appears to have addressed these patient expectations, allowing for return to previous activity level, and thus increasing reported satisfaction.

Arthroscopic Capsulorrhaphy. Several previous studies have reported a trend toward higher failure rates, (from 16 to 60%) with arthroscopic stabilization techniques using transglenoid sutures.[4, 14, 26] Conversely, we observed the highest success (86%) in patients managed with arthroscopic repair. Warner[18] observed a success rate (89%) similar to ours in a group of thirty-six patients with anterior instability managed with arthroscopy. An explanation for our findings may lie in surgical technique. Freedman and colleagues[14] recently conducted a meta-analysis evaluating open versus arthroscopic repair. These authors found significantly higher recurrence (defined as subluxation or dislocation) in arthroscopic repairs using transglenoid sutures or bioabsorbable tacks (20%) versus in open stabilization repairs (10%). However, they hypothesized that newer arthroscopic techniques that employ suture anchor fixation and capsular plication are likely to decrease recurrence, equaling that of open repair.[14] In our sample, 86% of this group underwent suture anchor repair, 14% were managed with bioabsorbable tacks, and no patients received the transglenoid suture repair. Our results suggest that newer techniques using suture anchors may indeed have resulted in the higher success rate we observed.

Failure / Revision Surgery

Clinical failure was defined in this study as postoperative episodes of instability (subluxation or dislocation), and/or a clinical ASES outcome of < 70/100. According to these criteria, eleven patients had unsatisfactory outcomes: five OC patients (24%), two AC patients (14%), and four TC patients (25%).

Patients managed with thermal capsulorrhaphy had the highest rate of recurrent instability. Three patients needed revision repair (19%), and four (25%) rated their shoulder as "poor" postoperatively. Of interest was the collegiate softball pitcher with MDI who reported excellent clinical results at three years follow-up, and later failed due to recurrent subluxation with pitching. D'Alessandro et al.[6] reported similar findings in a larger sample (twenty-two patients) of athletes with MDI. While 46% were doing well at one year follow up (ASES score of 91.5), clinical results deteriorated after longer follow-up evaluation.

However, our correlation analysis appears to contradict these findings. Although we did not directly compare outcomes by the length of follow-up period, it was interesting that the clinical results of our patients were not correlated ($r = -0.01$ to -0.16) with the length of follow-up period (*months post*), suggesting no appreciable deterioration in results as a function of time. In addition, follow-up period was not a significant predictor of either SRQ or ASES clinical scores. Because other evidence exists that clinical results diminish over time,[6, 26, 36] this relationship remains to be determined.

ASES and SRQ Results

The orthopedic literature is abundant with ASES clinical results following open and arthroscopic stabilization procedures (Table 7). Previously reported scores using the ASES evaluation tool ranged from 74-91/100 in arthroscopic repairs, to 75-97 in open repairs, and to 80-86 in thermal repairs. Fewer studies have evaluated patient-based SRQ outcomes; only one published study has evaluated thermal patients using this form (Table 8).

We observed overall mean ASES (80.6 ± 12.9) and SRQ (83.9 ± 11.6) scores comparable to previous reports (Table 7). No significant differences in ASES ($p = .12$) or SRQ ($p = .49$) clinical results existed between surgical groups. However, clinical results were significantly influenced by the type of preoperative instability ($p = .03$), and by postoperative episodes of subluxation ($p < .001$). That is, ASES results were significantly lower in patients with MDI versus those with traumatic, anterior instability (Table 9), and lower in patients exhibiting postoperative subluxation versus those without instability (Table 10).

TABLE 7
Summary of ASES Outcomes Following Shoulder Surgery

Authors	Subjects	Instability	Procedure(s)	ASES score	Months follow-up: (range)	Recurrence/ Failure
O'Neill, 1999	41 athletes	A	AB-TS	95% ≥ 80	52 (25-84)	5%
Warner, 2004	36 patients	A	AB-TS	83	37	9%
Gartsman, 2000	53 patients	AI	AB/TC	91	33 (26-63)	8%
Mazzocca, 2005	18 control/ coll athletes	A	AB/C	89	37 (24-66)	15% after 2 years
Potzl, 2004	14 patients	A	OB, AB	74.6	5.9 years	N/A
Gill, 1997	60 shoulders	A	OB		8 yrs minimum	N/?A
Pagnani, 2002	58 FB players	A	OB	97	37	4%
Enad, 2004	20 overhead athletes	A	TC	86	23	N/A
D'Alessandro, 2004	84 shoulders	MDI=63%, A=14%, S=23%	TC	83	37 (24-53)	Overall = 37% MDI = 41% AGHI = 25% Subtle = 31%
Sullivan, 2005	51 shoulders	A = 83% MDI=17%	AB/C, TC, OB/C	Overall = 81 AB/C = 86 TC = 80 OB/C = 77	32 (6-96)	Overall = 21% OC = 23% AC = 14% TC = 25%

A = Anterior instability
AI = Anterior-inferior instability
MDI = Multidirectional instability
S = Subtle instability (without dislocation)
AB = Arthroscopic Bankart repair
TS = Transglenoid suture stabilization technique
AB/C = Arthroscopic Bankart/Capsulorrhaphy
OB/C = Open Bankart/Capsulorrhaphy
TC = Thermal Capsulorrhaphy

TABLE 8
Summary of SRQ Outcomes

Authors	Subjects	Instability	Procedure	Postoperative SRQ mean score	Mean follow-up (range)
Wolf, 2004.	48	Posterior	OCS	81	(1.8-22.5 years)
Lephart, 2002.	20	A, AI, MDI	TC	92	12 months (6-24)
Sullivan, 2005	51	A, BDI, MDI	OC, AC, TC	OC=85, AC=85, TC=81	32 months (6-96)

TABLE 9
Comparison of ASES and SRQ Results by Diagnosed Instability.

Results:	N (%)	ASES Score	SRQ Score
Traumatic anterior instability	40 (78%)	82.3 ± 11.3*	85.3 ± 10.4
Subtle instability/subluxation	5 (10%)	80.2 ± 14.5	82.8 ± 15.5
Multidirectional instability	6 (12%)	71.0 ± 17.6*	73.7 ± 14.4

* Significant difference between patients with MDI and traumatic anterior instability (LSD, *P*=.03)

TABLE 10
Comparison of Patients With and Without Postoperative Instability.

Results:	N	ASES Score	SRQ Score
Subluxators	11	68.4 ± 13.8*	73.3 ± 14.4*
Non-subluxators	40	84.9 ± 9.9	87.3 ± 8.4

* Significantly lower than non-subluxators (*P*<.001)

The ASES results we observed in arthroscopic patients (mean score, 86.4/100 ± 8.5) are similar to those reported by Warner[18] (83) in thirty-six patients with anterior instability at similar follow-up (37 months). Interestingly, Gartsman et al.[16] observed higher clinical results (91) in patients with anteroinferior instability using thermal capsulorrhaphy as an adjunct to arthroscopic stabilization early in their clinical series. These authors emphasized that closure of the rotator interval improved outcomes.

Most recently, Potzl et al.[53] evaluated a limited sample of ten patients managed with open stabilization and four patients treated with arthroscopic Bankart repair, reporting slightly lower (74.6 ± 22.9) ASES scores than our OC patients (77.1 ± 13.1). Conversely, Pagnani[50] reported substantially higher mean scores (97) in fifty-eight football players managed with open Bankart repair. These authors restricted their sample to patients with anterior instability, which may explain their improved results.

We observed lower SRQ scores on average (80.5 ± 13.3) in thermal patients than open and arthroscopic patients. Lephart et al. [28] observed SRQ results higher than ours in twenty thermal patients (91.9 ± 5.4); however, their follow-up period was limited to one year.

Correlations between Objective and Subjective Outcomes.

The ASES evaluation form and the Shoulder Rating Questionnaire are validated clinical tools used to assess objective function and patient-based outcomes after surgery.[5, 10, 17, 28, 34, 49, 50, 54] We observed moderately high, significant correlations between these evaluative tools, demonstrating that patients' perception of the status of their shoulder, and their functional ability, were related to objective clinical evaluation. Because many current measurement scales are lacking patient-based assessment, we suggest that tools such as the SRQ be used concurrently with objective evaluation to provide a thorough clinical picture of surgical success after shoulder stabilization.

Regression Analysis

Our findings suggest that a patient's level of postoperative pain and ASES clinical outcome score significantly predicted their level of satisfaction with the surgically-repaired shoulder, as measured by the Shoulder Rating Questionnaire. Using the regression model, a patients' predicted SRQ clinical score was equal to 26.19 - 1.02 (PAIN SCORE) + .29 (ASES SCORE). Correlation analysis also demonstrated that pain level was significantly related to ASES scores.

Grant[21] stated that if a patient primarily desires a reduction of pain and an improvement in ROM, surgery is an effective option with a low complication rate. Our results suggest that a patient's level of pain is also a significant predictor of the satisfaction with and function of their surgical shoulder as measured by the SRQ. Additionally, Grant[21] concluded that a patient's perception of the effectiveness of surgery decreases if the primary stated goals of surgery are improved strength and function. The results of our regression analysis are in agreement with Grant in that a patient's shoulder strength profile was not predictive of clinician-based objective function (ASES score) or patient-based satisfaction (SRQ score).

Range of Motion

We were not surprised that the greatest amount of active external rotation loss of motion occurred in the open capsulorrhaphy group, with an average loss of 10.4° at 0° abduction and 13.4° at 90° abduction when compared with the patient's contralateral shoulder. Arthroscopic thermal repair resulted in the least (2.2°) loss of motion on average in the position of function (90° abduction).

Several potential criticisms of this study are evident. Because this was a retrospective study and patients were not randomized into surgical groups, the potential for selection bias existed. In addition, the direction and pattern of instability (subluxation versus dislocation) likely confounded clinical outcomes, making comparison between surgical groups difficult. Due to the retrospective nature of this study, patients did not follow a standardized rehabilitation protocol and its influence on postoperative outcomes is unclear.

In summary, arthroscopic capsulolabral repair was the most effective at preventing recurrent glenohumeral instability and resulted in high clinical outcome scores. Arthroscopy was clearly indicated over open repair for the overhead athlete with subtle instability; this approach appears to be as effective as open repair in eliminating symptoms of instability, while preserving the range of motion imperative for return to overhead sport. The recurrent subluxation rate was surprising in patients repaired with open stabilization. This was likely a function of preoperative instability and substantial osseous lesions as much as procedural failure.

Of greatest concern was the higher rate of failure, higher rate of revision surgery, and lower patient satisfaction observed among the thermal capsulorrhaphy patients. The success of thermal capsulorrhaphy is closely associated with proper patient selection; for example, MDI patients experienced particularly low clinical outcomes with the thermal technique.

Further data are needed to clarify both the high success rate we observed among patients managed with newer arthroscopic anchoring techniques, and the low success rate we observed among patients who underwent thermal capsulorrhaphy. Our findings support those of D'Alessandro and colleagues[6] who have advised the judicious and limited use of thermal repair until long-term data clarify its specific indications.

Clinical outcomes, including a patient's reported level of pain and the clinician-based ASES, are significant predictors of a patient's perception of surgical success and postoperative function. The strong correlation observed between objective clinical evaluation and patient-based satisfaction indicated agreement between the anatomic success of surgery and patients' perceptions of their repaired shoulders.

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CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDY

CONCLUSIONS

The objective of this research investigation was to compare postoperative clinical results among three common surgical techniques currently being used to manage patients with anterior glenohumeral instability (AGHI). Also of interest was the extent to which clinical measures of objective and subjective function are predictive of surgical success, as evidenced by a patient's level of postoperative satisfaction and functional ability. The following conclusions are warranted based upon the results of this investigation:

1. Arthroscopic capsulorrhaphy most effectively prevented recurrent anterior glenohumeral instability in our sample, and resulted in the highest objective clinical outcome scores. In contrast, patients who had their shoulders repaired with thermal capsulorrhaphy had the highest rates of recurrent instability and revision surgery.
2. Significant concentric strength deficits were observed in the involved shoulders of patients treated with open and thermal capsulorrhaphy. The most pronounced deficits occurred in the internal rotation strength of open capsulorrhaphy patients' repaired shoulders.
3. Open, thermal, and arthroscopic capsulorrhaphy each resulted in shoulder joint position sense (JPS) in patients' repaired shoulders equivalent to that of their uninjured shoulders. Patients who underwent open capsulorrhaphy demonstrated the best JPS acuity in their repaired shoulders.

4. Clinical outcomes, including objective clinical results (ASES score) and self-reported level of pain, accurately predict operative success as it relates to patient satisfaction and functional ability.

Overview of Research Challenges

My interest in this area of research began while supervising the rehabilitation programs of collegiate athletes treated by two orthopedic surgeons who helped pioneer thermal capsulorrhaphy, Dr. Gary Fanton and Dr. Michael Dillingham. The rationale for performing thermal capsulorrhaphy was that it would result in a quicker return to competition in elite collegiate overhead athletes. The clinical use of thermal capsulorrhaphy has proliferated in the absence of long-term data evaluating the effects of thermal energy applied to *in vivo* human glenohumeral structures. Thus, a clear need has existed for a study evaluating postoperative outcomes following thermal capsulorrhaphy as compared with traditional open and arthroscopic procedures to prevent recurrent AGHI.

Data collection for this investigation has spanned two states and has included patients referred from nearly 20 orthopedic surgeons. A few research difficulties have occurred in the process that may provide insights for future investigations. The recruitment of surgical patients to participate in this study was extremely challenging. Initial attempts to meet with orthopedic surgeons in Oregon and California were repeatedly unsuccessful. The most successful methods of subject recruitment were advertisements via campus email and the student newspapers of Oregon State University and Point Loma Nazarene University. The introduction of Health Insurance Portability and Accountability Act (HIPAA) laws for the protection of patient confidentiality went into effect in the United States in April 2003. Constraints associated with HIPAA hindered my ability to recruit surgical subjects from orthopedic and rehabilitation clinics. In order to gain access to confidential patient information, a modification was made to the original informed consent documents approved in 2001, with subjects' signatures authorizing the release of their medical information. The OSU Institutional Review Board for the Protection of Human Subjects requested that this modification be removed; therefore, it is not included in Appendix B.

In addition, my move from Oregon to California resulted in data collection challenges associated with two testing sites. However, I established a data collection site at the San Diego Chargers athletic training facility. As a result, nearly 20 subjects were tested using the dynamometer located in their facility, and subsequent "field trips" to the Chargers NFL training facility are now a component of two athletic training courses that I instruct at Point Loma Nazarene University in San Diego.

Strengths and Weaknesses

This investigation was the first to directly compare subjective and objective outcomes in patients after thermal, open, and arthroscopic glenohumeral capsulorrhaphy to address AGHI. The evaluation of outcomes at a mean follow-up period of nearly three years expands the current body of knowledge and improves the level of confidence in the clinical findings. By incorporating a sex-matched and age-matched control group, comparisons were possible of subjective and objective outcomes between surgically-repaired patients and "normal" subjects. Including a group of normal, healthy control subjects allowed for concentric strength outcomes to be compared between surgical patient's involved shoulders and control subject's nondominant shoulders, since some data has demonstrated significant, dominant versus nondominant limb differences. Further, comparison of JPS acuity in patients' repaired shoulders with controls normal shoulder demonstrated that surgically-repaired shoulders had better JPS acuity than uninjured subjects' dominant shoulders. Assessment of both clinician-based and patient-based clinical outcomes provided a more accurate clinical picture of patient status after repair of AGHI. While assessment of patient-based outcomes is typically lacking in orthopedic research, our results demonstrate that these outcomes are important predictors of surgical success to address shoulder instability.

There are several potential criticisms of this study. The inclusion of patients from multiple orthopedic surgeons introduced individual variation in both the performance of and experience with particular surgical techniques. The extent to which these variations confounded the clinical results is indeterminate. A different perspective on this issue is that the recruitment of patients from a dozen surgeons from two different states who performed the same operative technique actually increased the generalizability of these findings, rather than limiting the subject pool to one orthopedist's group of patients.

Due to the retrospective nature of this study, patients did not follow a standardized rehabilitation protocol. Therefore, the influence of rehabilitation on postoperative outcomes could not be ascertained.

In addition, the potential for selection bias existed as patients were not randomly assigned to surgical groups. The highest level in the hierarchy of clinical evidence involves prospective, randomized, controlled clinical trials. Although randomization to a particular surgery can be impractical and even inappropriate, a prospective, controlled research design would likely have answered some persisting questions that this research design was unable to address.

Recommendations for Future Research

A prospective research design is necessary to evaluate preoperative and postoperative clinical outcomes similar to those used in this investigation to answer the following questions:

a. Do patients with glenohumeral instability possess preoperative deficits in proprioception in both the involved and the contralateral, uninvolved shoulders?

b. If preoperative deficits in proprioception exist, are these deficits actually "restored" with surgical repair of anterior glenohumeral instability? If so, which surgical procedure is optimal for restoring shoulder proprioception?

The process of evaluation of subjective and objective outcomes must be extended beyond four years postsurgery. Long-term clinical results evaluating patients treated with newer arthroscopic procedures, e.g., thermal capsulorrhaphy, arthroscopic Bankart repair with suture anchors, and arthroscopic capsular plication, remain to be compared with clinical results of open capsulorrhaphy.

The assessment of a battery of neuromuscular outcomes should be conducted in patients with glenohumeral instability, and in patients repaired with open, arthroscopic, and thermal procedures compared with normal control subjects. Patients with a total shoulder arthroplasty (joint replacement) should also be compared with the previous groups to determine the influence of glenohumeral capsular mechanoreceptors on these outcomes. The battery of neuromuscular tests should be expanded to include:

a. Reflex latencies of selected glenohumeral musculature in response to unexpected anterior and posterior perturbations in the "position of vulnerability" (90° of glenohumeral abduction and external rotation).

b. Active reproduction of actively-placed joint positions (ARAP) should be evaluated in lieu of passive reproduction of passive positioning (PRPP).

Summary of Research Findings

Open glenohumeral capsulorrhaphy has been traditionally preferred to arthroscopic stabilization for limiting recurrent AGHI. However, arthroscopic repairs utilize less invasive approaches in stabilizing the shoulder, resulting in a quicker recovery of internal rotation strength and external rotation range of motion. Further, arthroscopy was more effective than open and thermal repair in preventing recurrent episodes of AGHI. These clinical results indicate that arthroscopic repair is preferable to open repair for active patients who desire to participate in functional overhead activities after surgery.

Glenohumeral proprioception and functional ability in patients treated with thermal capsulorrhaphy were comparable to patients managed with open and arthroscopic capsulorrhaphy. However, the increased rates of failure and revision surgery, decreased ability to return to activity and lower reported satisfaction of thermal capsulorrhaphy patients enumerated in this investigation highlights the necessity for the judicious and limited use of this procedure until long-term data are generated.

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APPENDICES

APPENDIX A

APPLICATION FOR APPROVAL OF THE OSU INSTITUTIONAL REVIEW BOARD (IRB) FOR THE PROTECTION OF HUMAN SUBJECTS

Principal Investigator: Rod A. Harter, Ph.D., ATC

Email:	rod.harter@oregonstate.edu
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Department:	Exercise and Sport Science
Project Title:	**Evaluation of Postoperative Outcomes Following Thermal and Open Glenohumeral Capsulorrhaphy**
Type of Project:	Student thesis
Student Investigator:	Jeff A. Sullivan, MA, ATC
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Type of review:	**Full board**

Signed: ______________________________ **Date:** ___________

Principal Investigator

Project Title: Evaluation of Postoperative Outcomes Following Thermal and Open Glenohumeral Capsulorrhaphy

1. Description.

Shoulder joint instability is a common problem that affects many athletic individuals; this problem is often difficult to resolve, even with surgery. A variety of surgical procedures are currently used to treat shoulder instability, including traditional arthrotomy (open joint) procedures, and newer arthroscopic techniques that are considered less invasive. The traditional procedure to repair shoulder instability is an open capsulorrhaphy, a term derived from the Latin roots *capsula*=capsule, and *rhaphë*=suture). The surgeon enters the shoulder joint capsule with an incision, cutting through several layers of tissue, and tightens the ligamentous capsule by creating flaps of tissue and pulling them together with sutures. In arthroscopic capsulorrhaphy procedures, the surgeon utilizes an arthroscope (a lighted, hollow instrument hooked directly to a viewing monitor) to visualize the shoulder joint capsule through a small portal rather than cutting through overlying tissue to directly visualize the joint. Recently, thermal energy (heat) has been introduced into arthroscopic procedures by using either a laser or radiofrequency device to thermally shrink the shoulder joint structures which have become slack or redundant. This procedure, known as thermal capsulorrhaphy, has been effective in improving shoulder joint stability. However, the medical community currently considers thermal capsulorrhaphy to be experimental, primarily because no data exist on the long-term effects of thermal energy applied to human collagen tissues. Despite its investigational status, sports medicine orthopedic surgeons are employing thermal capsulorrhaphy in an increasing number of surgical procedures. No long term follow-up studies of thermal capsulorrhaphy exist. Therefore, it is necessary to evaluate how patients perform on standard shoulder function tests after such procedures. The purpose of this proposed study is to compare shoulder muscular strength, proprioception (the ability to sense joint position and movement), and overall patient satisfaction in subjects who have had either a thermal capsulorrhaphy or a traditional open capsulorrhaphy procedure. This research is important to the field of athletic training/sports medicine because it will provide new information concerning the effects of thermal and open capsulorrhaphy on shoulder function and patient satisfaction following surgery. These results can be used by allied healthcare practitioners to more effectively treat patients with anterior shoulder instability.

2. Methods and Procedures.

A total of 60 adults (men and women, age range 18-50) will be recruited to participate in this study. Forty individuals who have undergone surgery for the correction of shoulder instability will be referred by the orthopedic surgeon who performed their surgery as potential candidates for participation. Twenty normal subjects with no history of shoulder injury will be recruited as an age and gender-matched control group. Age matching is being employed because previous studies have demonstrated that joint proprioception differs significantly between people of different ages, which could confound study results. All control subjects will undergo clinical examination by the doctoral student investigator (JAS) to verify that no shoulder pathology exists. Surgical subjects will also have their shoulder examined by JAS.

The first meeting between the doctoral student investigator (JAS) and each subject will take place in either the OSU Sports Medicine Laboratory in the Women's Building, Room #8, or the San Diego Chargers athletic training clinic in San Diego, California.. Potential subjects will read the informed consent document (Attachments #1a & 1b) and provide informed consent prior to the study if they agree to participate. Following the first meeting, each *surgical* subject will be evaluated by their orthopedic surgeon who will measure six domains of objective shoulder function using the American Shoulder and Elbow Surgeons (ASES) Shoulder Evaluation Form (Attachment #2). Each *control* subject will have objective shoulder function evaluated by the doctoral student investigator (JAS) using the same ASES Shoulder Evaluation form. The doctoral student investigator is a certified athletic trainer who possesses the necessary skills to assess shoulder joint function using the ASES form. In addition, each *surgical* subject will complete the Shoulder Rating Questionnaire (Attachment #3), which is intended to assess overall patient satisfaction with the surgically repaired shoulder.

All subjects will then have measures of proprioception, and shoulder strength (internal and external rotation peak torque values) conducted at either the OSU Sports Medicine Laboratory or the San Diego Chargers athletic training clinic using a Biodex dynamometer designed for such measurements (Figure 1). The entire data collection session will last approximately 90 minutes (Figure 1). In addition, neuromuscular control of the shoulder will be evaluated using a SportsRAC™ system (SportsTrac Systems, Inc, Boulder, CO) (Figure 2). All data will be collected and compared at two postoperative intervals ("short-term" = < 2 years, and "intermediate" = 2.1 to 4 years following surgery).

We will utilize two methods, which have been well-documented in the literature, to assess shoulder joint proprioception in this study: (a) passive reproduction of passive positioning (RPP), a common method used to assess the subject's ability to sense shoulder joint *position*; and (b) neuromuscular control, the ability to use fine motor control to actively change joint position in response to visual cues.

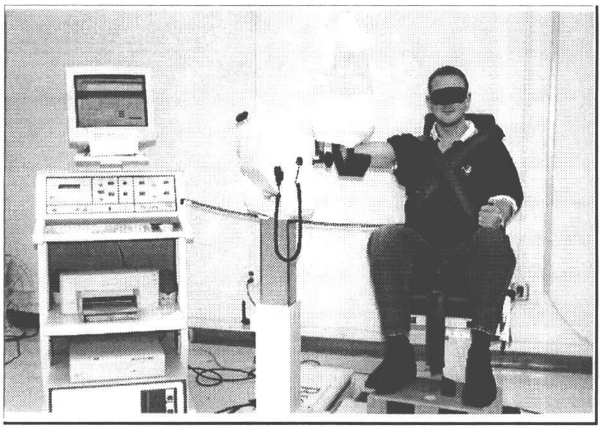

Figure 1. The Biodex MultiJoint System 3 Isokinetic Dynamometer will be used to measure joint position sense and isokinetic strength.

Joint Position Sense Testing. For passive reproduction of passive position (PRPP) measures, subjects will be asked to passively reproduce a variety of passively positioned shoulder joint angles. Testing will be performed in a single session with the order of injured and uninjured shoulder and target angles being counterbalanced to control for learning and fatigue. Subjects will be seated on the dynamometer in a comfortable position (Figure 1) similar to the standard position used in rotator cuff strength testing and rehabilitation protocol. The subject's shoulder will be secured to the dynamometer's lever arm by means of an elastic bandage. A stockinette and vacuum splint will be placed over the subject's forearm and arm to minimize sensory input from the skin and hair. The subject will be tested from a functional starting position in the frontal plane (90° of shoulder abduction, and 90° elbow flexion). After a standardized warm-up (which will acquaint the subject with the dynamometer through practice trials) we will employ the continuous passive motion (CPM) mode of the Biodex to have the subject identify two passively positioned joint angles, individually calculated for them at 60% and 90% of their maximum voluntary passive external rotation range of motion. The shoulder under investigation will be passively rotated by the Biodex using the CPM feature at a speed of 10°/sec to one of the two target angles. The target angle will be maintained for 3 seconds and the arm will be passively returned to the starting position by the device. The subjects will use the Biodex's cutoff switch to stop the CPM of their shoulder when they perceive the target angle has been reached. The accuracy of PRPP will be calculated as the absolute difference between the particular target angle and the joint position that the subject identifies as being that angle (in degrees). Three trials will be averaged for absolute target angle error for each of the 10 RPP tasks on each shoulder. The error values will be compared between injured and uninjured shoulders for each group of subjects.

Isokinetic Strength Testing: Following proprioception testing, subjects will have their shoulder joint strength evaluated using the Biodex dynamometer. Concentric internal and external rotation strength will be measured using 5 maximal testing repetitions at 90°/sec, 180°/sec, and 270°/sec. These speeds are commonly used to assess muscular strength in the shoulder joint. Prior to isokinetic testing, subjects will warm-up using an upper-body stationary ergometer ("arm-bike") for 10 minutes at a submaximal level. To acquaint subjects with the dynamometer, a warm-up will consist of 3 submaximal repetitions at each speed. The untreated shoulder will be tested first, followed by the surgically-treated shoulder. Five maximal concentric repetitions at each velocity will be used to obtain peak torque values.

3. Benefits.

The information gained from this research will aid physicians, athletic trainers, physical therapists, and the medical community in treating patients with shoulder instability by increasing the body of knowledge concerning strength and proprioception after thermal capsulorrhaphy. Subjects will receive a complimentary follow-up medical examination by their physician. In addition, the investigators have received funding for $2500 from the National Athletic Trainers' Association and for $3000 from the Northwest Health Foundation. Subjects will receive compensatory benefit of $50 for completing the proposed study.

4. Risks.

Foreseeable risks to the subject are minimal. During strength and proprioception testing, the dynamometer may allow the subject's shoulder to approach uncomfortable ranges of motion. However, all subjects must be at least 12 months post-surgery and must be cleared by their physician and discharged from rehabilitation, e.g., fully functioning. Further, the subject will always have an emergency shut-off switch and can activate the switch at any point during testing to completely disengage the dynamometer should they feel any discomfort.

Strength testing exercises may result in mild muscle soreness for 24-48 hours following the testing procedure. However, as previously mentioned, an adequate warm-up period will be performed by each subject before testing procedures are begun. The warm-up will significantly reduce any potential shoulder muscular soreness and will acquaint the subject with the dynamometer and the testing velocities.

4. Subject Population.

Sixty subjects (female and male, ages 18 to 50) who either have undergone thermal capsulorrhaphy (n = 20), open capsulorrhaphy (n = 20), or are apparently healthy controls (n = 20) will be recruited to participate in this study. Subjects will be divided into groups according to the surgical procedure performed on their injured shoulder, i.e., Group 1 = thermal capsulorrhaphy; Group 2 =open capsulorrhaphy. Control subjects will be age- (±10 years) and gender-matched with the subjects in the surgical groups. Orthopedic surgeons affiliated with medical groups in the Corvallis, Eugene, and Bend, Oregon areas have agreed to help in the recruitment of subjects for this study. We will seek permission to access medical files from patients who have had either a TC or OC procedure performed on their shoulder in the previous five years. For inclusion in the subject pool, patients must be at least one year post-surgery and possess a normal opposite shoulder for comparative purposes. All subjects must be 18 years of age or older, and members of Groups 1 & 2 must be cleared by their orthopedic surgeon and discharged from rehabilitation.

5. Informed Consent Process.

All potential subjects involved in this study will be informed of study procedures, intent of the study, and potential benefits and risks during the first meeting between the doctoral student investigator and the subject that will take place in either the OSU Sports Medicine Laboratory or the San Diego Chargers athletic training clinic prior to the initiation of the study. Potential subjects will read the Informed Consent document and will provide informed consent if they agree to participate.

6. Anonymity or Confidentiality.

The results of this investigation may be published; however, subject anonymity will be insured by the use of codes (subject ID numbers) on all data-collection forms in lieu of names. The master copy linking subject names with codes will be kept by the doctoral student investigator (JAS) and will be stored in a locked filing cabinet.

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APPENDIX B

INFORMED CONSENT DOCUMENT: *Surgical Subjects*

Title: Evaluation of Postoperative Outcomes Following Thermal and
Open Glenohumeral Capsulorrhaphy

Investigators: Jeffrey A. Sullivan, MA, ATC, Doctoral Student
Rod A. Harter, PhD, ATC, Associate Professor

Purpose: To measure shoulder strength, proprioception, (ability to perceive shoulder joint position and movement) and neuromuscular control (the ability to use fine motor control to actively change joint position in response to visual cues) to determine if these qualities are improved following shoulder surgery. I will be assigned to a group according to the type of surgery performed on my shoulder, and my results will be compared to a group of people similar in age who have never had shoulder surgery.

Procedures: I understand that if I agree to participate in this study my involvement will be for a single testing session in the Sports Medicine Laboratory lasting approximately 60-90 minutes.

Pre-study screening: my eligibility has been determined because I meet all of the following:

a. I am over 18 years of age.
b. I have had surgery on my shoulder in the past 5 years, have been discharged by my physician, and have been released from rehabilitation.

Participation Requirements: I understand that I will be a member of one of the following surgical groups based on the surgery that was performed on my shoulder:

(Place a checkmark or "X" next to the group that describes the surgical procedure performed on your shoulder.)

☐ *Thermal capsulorrhaphy group:* I have had a thermal capsular repair of my shoulder within the past 5 years. This was an arthroscopic surgical procedure that used a laser to heat and shrink my shoulder joint capsule in order to make my joint more stable.

☐ *Open capsulorrhaphy group:* I have had an open capsular repair of my shoulder within the past 5 years. The goal of this procedure was to make my shoulder more stable by pulling the damaged ligaments closer together and holding them in place with stitches.

As a participant in this study, I understand that I will be asked to fulfill the following requirements:

a. I will have shoulder strength, proprioception, and neuromuscular control tested in both of my shoulders. I understand that each shoulder will have three sets of tests conducted using a computerized testing device (Biodex Isokinetic Dynamometer) in the Sports Medicine Laboratory in the Women's Building at Oregon State University. First, I will be asked to replicate a variety of shoulder joint positions by starting and stopping the Biodex device. Second, I will move the Biodex device against resistance and the device will measure my shoulder strength. Third, a measurement will be taken on my ability to actively stabilize and control the position of my shoulder joint by contracting my shoulder muscles. These measurements will be compared between my shoulders, as well as with other subjects having a different type of surgery, and with control subjects. These tests will be completed in about 60-90 minutes.
b. I will have my shoulder that had surgery evaluated in terms of pain, range of motion, strength, stability, and function. In addition, I will be asked to complete a shoulder rating questionnaire that will ask questions about how my shoulder feels since surgery was performed.

Foreseeable Risks or Discomforts: Foreseeable risks to myself are minimal. I understand that during strength, proprioception, and neuromuscular control testing, the dynamometer may allow my shoulder to approach uncomfortable position(s). I also understand that I will have an emergency shut-off switch that will stop the Biodex at any point during testing.

I understand that the strength testing exercises may result in mild muscle soreness for 24-48 hours following the testing procedure. However, it has been explained to me that a warm-up procedure will be conducted to reduce potential soreness and to acquaint me with the dynamometer.

Benefits Expected from Research: I understand that I will have my surgically treated shoulder evaluated by the researchers free of charge. Also, the information gained from this research will aid physicians, athletic trainers, physical therapists, and the medical community in treating patients with shoulder instability by increasing the body of knowledge concerning strength and proprioception after shoulder surgery.

Compensation: I understand that as compensation for my participation, I will receive $50. I understand that if I withdraw from the study before it is completed, I will receive no compensation

Confidentiality: The results of this investigation may be published, but my name or identity will be protected to the extent permitted by law. A random number assigned to me will maintain my confidentiality. This number will be used rather than my name on all data collection and analysis forms. Only the researcher, Jeff Sullivan, will have the key that matches my name with a random number. This key will be stored in a locked filing cabinet.

Compensation for Injury: I understand that Oregon State University does not provide a research subject with compensation or medical treatment in the event the subject is injured as a result of participation in this research project.

Voluntary Participation Statement: I understand that my participation in this study is completely voluntary and that I may either refuse to participate or withdraw from the study at any time.

If You Have Questions: Further questions about this research study, or research injuries should be directed to Dr. Rod A. Harter, Women's Building, Oregon State University, Corvallis, Oregon at (541) 737-6801, or to Jeff Sullivan at (541) 737-6899.

If I have questions about my rights as a subject participating in this research, I can contact the Oregon State University Institutional Review Board (IRB) Human Protection Administrator at (541) 737-3437 or by e-mail at IRB@oregonstate.edu

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My signature below indicates that I have read and that I understand the procedures previously described and give my informed and voluntary consent to participate in this study. I understand that I will receive a signed copy of this consent form.

Subject's Signature:____Date:_________

Subject's Name (printed):____

Signature of investigator:____________________________________Date:_________

My signature below indicates that I consent to the release of the operative report form my medical file to the researchers of this study (Jeff Sullivan and Rod Harter only).

Subject's Signature:____Date:_________

APPENDIX C

AMERICAN SHOULDER AND ELBOW SURGEONS' SHOULDER EVALUATION FORM

Subject ID#: ________________ Physician: ________________ Date: ________________ Shoulder: R / L

I. Pain:

5 none
4 slight
3 after unusual activity
2 moderate
1 marked
0 complete disability
NA not available)

II. Motion:

A. Patient Sitting

1. Active total elevation of arm __________ degrees

2. Passive internal rotation: (Circle the segment of posterior anatomy reached by thumb. Note if reach is restricted by limited elbow flexion)

1= Less than trochanter 5=L5 9=L1 13=T9 17=T5
2=Trochanter 6=L4 10=T12 14=T8 18=T4
3=Gluteal 7=L3 11=T11 15=T7
19=T3
4=Sacrum 8=L2 12=T10 16=T6
20=T2

3. Active external rotation with arm at side:______________degrees

4. Active external rotation at 90 abduction:______________degrees
(Enter "NA" if cannot achieve 90 of abduction)

B. Patient Supine

1. Passive total elevation of arm:______________________degrees*

2. Passive external rotation with arm at side:______________degrees

* Total elevation of arm is measured by viewing patient from side and using goniometer to determine angle between the arm and the thorax.

III. Strength: (5=normal, 4 = good, 3=fair, 2=poor, 1=trace, 0=paralysis)

A. Anterior deltoid _____ C. External rotation _____

B. Middle deltoid _____ D. Internal rotation _____

IV. Stability:

5 = normal
4 = apprehension
3 = rare subluxation
2 = recurrent subluxation
1 = recurrent dislocation
0 = fixed dislocation
NA = not available

A. Anterior ________ B. Posterior ________ C. Inferior ________

AMERICAN SHOULDER AND ELBOW SURGEONS' SHOULDER EVALUATION FORM

V. Function: (4 = normal, 3 = mild compromise, 2 = difficulty, 1 = with aid, 0 = unable, NA = not available)

A. Use back pocket ________
B. Perineal care ________
C. Wash opposite axilla ________
D. Eat with utensil ________
E. Comb hair ________
F. Use hand with arm at shoulder level ________
G. Carry 10—15 lb. with arm at side ________
H. Dress ________
I. Sleep on affected side ________
J. Pulling ________
K. Use hand overhead ________
L. Throwing ________
M. Lifting ________
N. Do usual work (specify) ________
O. Do usual sport (specify) ________

VI. Patient Response:

3 = much better

2 = better

1 = same

0 = worse

NA = not available/applicable ________

Source: American Shoulder and Elbow Surgeons shoulder evaluation form. (Courtesy of the American Shoulder and Elbow Surgeons).

APPENDIX D

SHOULDER RATING QUESTIONNAIRE

A SELF-ADMINISTERED QUESTIONNAIRE FOR ASSESSMENT OF SYMPTOMS AND FUNCTION

Subject ID#____________Date ________ Dominant arm (circle one): L / R Evaluated or treated shoulder: L / R

Please answer the following questions regarding the shoulder for which you have been evaluated or treated. If a question does not apply to you, leave that question blank.

1. Considering all the ways that your shoulder affects you, mark X on the scale below for how well you are doing.

Very poorly____Very well

The following questions refer to pain:

2. During the past month, how would you describe the usual pain in your shoulder <u>at rest</u>?
   - A) Very severe
   - B) Severe
   - C) Moderate
   - D) Mild
   - E) None

3. During the past month, how would you describe the usual pain in your shoulder <u>during activities</u>?
   - A) Very severe
   - B) Severe
   - C) Moderate
   - D) Mild
   - E) None

4. During the past month, how often did the pain in your shoulder make it <u>difficult for you to sleep</u> at night?
   - A) Every day
   - B) Several days per week
   - C) One day per week
   - D) Less than one day per week
   - E) Never

5. During the past month, how often have you had <u>severe pain</u> in your shoulder?
   - A) Every day
   - B) Several days per week
   - C) One day per week
   - D) Less than one day per week
   - E) Never

The following questions refer to daily activities:

6. Considering all the ways you use your shoulder during daily personal and household activities (i.e. dressing, washing, driving, household chores, etc.), how would you describe your ability to use your shoulder?
   A) Very severe limitation; unable
   B) Severe limitation
   C) Moderate limitation
   D) Mild limitation
   E) No limitation

Questions 7-11: During the past month, how much difficulty have you had in each of the following activities due to your shoulder?

7. Putting on or removing a pullover sweater or shirt.
   A) Unable
   B) Severe difficulty
   C) Moderate difficulty
   D) Mild difficulty
   E) No difficulty

8. Combing or brushing your hair.
   A) Unable
   B) Severe difficulty
   C) Moderate difficulty
   D) Mild difficulty
   E) No difficulty

9. Reaching shelves that are above your head.
   A) Unable
   B) Severe difficulty
   C) Moderate difficulty
   D) Mild difficulty
   E) No difficulty

10. Scratching or washing your lower back with your hand.
   A) Unable
   B) Severe difficulty
   C) Moderate difficulty
   D) Mild difficulty
   E) No difficulty

11. Lifting or carrying a full bag of groceries (8 to 10 pounds, 3.6 to 4.5 kilograms).
   A) Unable
   B) Severe difficulty
   C) Moderate difficulty
   D) Mild difficulty
   E) No difficulty

The following questions refer to recreational or athletic activities:

12. Considering all the ways you use your shoulder during recreational or athletic activities (i.e. baseball, golf, aerobics, gardening, etc.), how would you describe the function of your shoulder?

A) Very severe limitation; unable
B) Severe limitation
C) Moderate limitation
D) Mild limitation
E) No limitation

13. During the past month, how much difficulty have you had throwing a ball overhand or serving in tennis due to your shoulder?

A) Unable
B) Severe difficulty
C) Moderate difficulty
D) Mild difficulty
E) No difficulty

14. List one activity (recreational or athletic) that you particularly enjoy and then select the degree of limitation you have, if any, due to your shoulder.

Activity ______________________________

A) Unable
B) Severe limitation
C) Moderate limitation
D) Mild limitation
E) No limitation

The following questions refer to work:

15. During the past month, what has been your main form of work

A) Paid work (list type______________________________
B) Housework
C) Schoolwork
D) Unemployed
E) Disabled due to your shoulder
F) Disabled secondary to other causes
G) Retired

If you answered D, E, F, or G to the above question, please skip questions 16-19 and go on to question 20.

16. During the past month, how often were you unable to do any of your usual work because of your shoulder?

A) All days
B) Several days per week
C) One day per week
D) Less than one day per week
E) Never

17. During the past month, on the days that you did work, how often were you unable to do your work as carefully or as efficiently as you would like because of your shoulder?

A) All days
B) Several days per week
C) One day per week
D) Less than one day per week
E) Never

18. During the past month, on the days that you did work, how often did you have to work a shorter day because of your shoulder?

A) All days
B) Several days per week
C) One day per week

D) Less than one day per week
E) Never

19. During the past month, on the days that you did work, how often did you have to change the way that your usual work is done because of your shoulder?

A) All days
B) Several days per week
C) One day per week
D) Less than one day per week
E) Never

The following questions refer to satisfaction and areas for improvement.

20. During the past month, how would you rate your over-all degree of satisfaction with your shoulder?

A) Poor
B) Fair
C) Good
D) Very good
E) Excellent

21. Related to your shoulder, please rank the two areas in which you would most like to see improvement (place a "1" for the most important, a "2" for the second most important).

Pain ________
Daily personal and household activities ________
Recreational or athletic activities ________
Work ________

This is the end of the Shoulder Rating Questionnaire.

Thank you for your cooperation.

Source: L'Insalata JC, Warren RF, Cohen SB, Altchek DW, Peterson MGE: A self-administered questionnaire for assessment of symptoms and function of the shoulder. J Bone Joint Surg 1997; 79-A: 738-748.

APPENDIX E

Review of Literature

OPEN VERSUS ARTHROSCOPIC MANAGEMENT OF ANTERIOR GLENOHUMERAL INSTABILITY:

A Review of Treatment Options for the Unstable Shoulder

ABSTRACT

Over the past few decades, considerable advances have been made in the surgical management of anterior glenohumeral instability. Although arthroscopic approaches initially resulted in high failure rates compared with open approaches, the most current results indicate that outcomes between the two procedures are comparable, and may even be equivalent, if the surgical procedure is chosen on the basis of specific pathoanatomy involved with the instability. Innovative arthroscopic techniques such as thermal capsulorrhaphy and suture anchors are being increasingly used during arthroscopy and are effective in addressing coexisting pathology such as a Bankart lesion and associated capsular attenuation. Further, these techniques are becoming popular because they are associated with decreased surgical morbidity, decreased surgical time, and lower levels of post-surgical pain. However, long-term data on their efficacy and safety are necessary before these techniques can be considered enduring successes. This review of literature discusses and evaluates three prevalent techniques for the management of the unstable shoulder. Functional outcomes following these stabilization procedures are examined to determine the efficacy of each. Also, a pathology-based algorithm is presented that may be an effective tool to aid clinicians in the selection of appropriate surgical procedures for patients with anterior shoulder instability.

INTRODUCTION

Anterior glenohumeral joint instability (AGHI) in the physically-active individual presents a significant challenge for today's orthopaedic practitioner in terms of assessment, treatment, and surgical management. Over the past 20 years, a number of surgical approaches have been advocated to address the primary pathologic components of AGHI—capsulolabral injury and a redundant or excessively lax glenohumeral joint capsule. Traditional surgical procedures involving arthrotomy, i.e. open Bankart/capsular shift, as well as recent advances in arthroscopy, i.e. arthroscopic Bankart, laser/radiofrequency thermal capsulorrhaphy, have attempted to stabilize the shoulder joint while concurrently maintaining optimal joint function.

This paper has two primary aims: (a) to present an appreciation for anatomic structures that are essential to glenohumeral stability, identify a novel approach to the classification of instability as a spectrum of injury, and discern the pathophysiology involved with shoulder instability; and (b) to present an overview of three widely used surgical stabilization procedures—open Bankart/capsular shift, arthroscopic Bankart repair, and thermal capsulorrhaphy—reviewing current literature on surgical outcomes following these techniques. Surgical outcomes can be used to indicate the efficacy of each procedure for the treatment of shoulder instability. The purpose of reviewing results of each procedure is to determine the optimal method of stabilization for the individual patient with an unstable shoulder.

ANTERIOR GLENOHUMERAL INSTABILITY (AGHI)

An appreciation of the integrative functions of the static and dynamic stabilizers of the glenohumeral joint is imperative to understanding the pathoetiology of AGHI

(Table 1). Static and dynamic stability is provided by the combined efforts of the capsuloligamentous structures, the rotator cuff, the scapular stabilizers and the biceps muscle. [15,22,25] Any imbalance of this relationship may contribute to AGHI, particularly in the physically-active individual.

TABLE 1. Stabilizers of the Glenohumeral Joint

Static Stabilizers	Dynamic Stabilizers	
Capsule	Supraspinatus	Humeral stabilizers
Labrum	Infraspinatus	
Coracohumeral ligament	Subscapularis	
Superior GH ligament	Teres minor	
Middle GH ligament	Pectoralis major	Glenohumeral joint movers
Geometry of humeral surface	Latissimus dorsi	
Geometry of glenoid surface	Teres major	
Coracoacromial ligament	Biceps brachii	
Articular cartilage compliance	Triceps brachii	
Joint cohesion—negative pressure	Deltoid	
	Serratus Anterior	Scapular stabilizers
	Latissimus dorsi	
	Trapezius	
	Rhomboids	
	Levator scapulae	
	Pectoralis minor	

Anatomy of Shoulder Stability.

Pathology to an array of structures may contribute to glenohumeral joint stability. (Table 1) The unique stabilizing contributions of a few essential structures have recently been elucidated and are discussed here.

The ligamentous structures of the glenohumeral joint function primarily in extreme ranges of motion to prevent excessive translation and rotation. O'Brien et al.[23] demonstrated the unique contribution of the inferior glenohumeral ligament complex (IGHLC) to shoulder stability, identifying it as the main static stabilizer to both anterior and posterior translation in the abducted shoulder. Using 11 cadavers, O'Brien et al. showed that the IGHLC is comprised of anterior and posterior bands that reciprocally tighten during anterior and posterior translation, respectively. This function serves to prevent excessive translation when the glenohumeral joint is in 90° of abduction and rotation. Thus, the IGHLC is intimately fashioned around the humeral head, acting as a "hammock" of support as it rotates in a functionally abducted position.[23] O'Brien et al. concluded that the anatomic arrangement of the components of the IGHLC may provide the key to understanding both anterior and posterior stability in the shoulder.

It is well-established that the rotator cuff contributes significantly to joint stability through dynamic action, compressing the humeral head into the glenoid fossa, particularly in the midranges of motion.[4,15,16,18] Indeed, the rotator cuff is ideally positioned to provide a compressive load throughout full glenohumeral range of motion[16]; thus, it is often referred to as the "compressor cuff" as it creates an inferomedial vector of pull on the humeral head to center it in the glenoid. Additional dynamic support is provided by the long head of the biceps muscle-tendon (LHBT). Rodosky et al[25] showed that the LHBT contributes to glenohumeral stability by depressing the humeral head and resisting external rotation forces that occur when the shoulder is in the abduction and external rotation position, the so-called "position of vulnerability". The LHBT serves an important role in decreasing stress placed on the IGHLC in this precarious position.

Kibler[15] recently described the crucial role of the scapula in shoulder injury and overall GH joint function, suggesting that its importance has previously been misunderstood. He elucidated five important functions of the scapula in maintaining GH stability: (a) stability of the GH articulation, maintaining the ball-and-socket configuration, (b) protraction and retraction of the scapula, facilitating GH acceleration and deceleration, (c) elevation of the acromion to prevent subacromial or coracoacromial impingement, (d) base of support for attachment of rotator cuff and extrinsic muscles, and (e) "funnels" and transfers tremendous force generated from larger segments of the kinetic chain to the final links, i.e., arm, hand. Perhaps the most vital role of the scapula is its role as a stable base for the attachment of the rotator cuff muscles and other glenohumeral movers. According to Kibler, the inability of the scapula to perform any of its functions may be the catalyst for many cases of shoulder instability.[15]

The fibrocartilaginous labrum provides increased stability to the glenohumeral joint by deepening the articulation of the humeral head on the glenoid, acting as a "bumper" or a "chock block", preventing the humeral head from rolling over the glenoid. Because of its importance for maintaining stability, nearly all labral lesions are thought to contribute to GH instability.[4] Indeed, Bankart referred to an anterior/inferior labral lesion as the "essential lesion" contributing to recurrent anterior instability.[5]

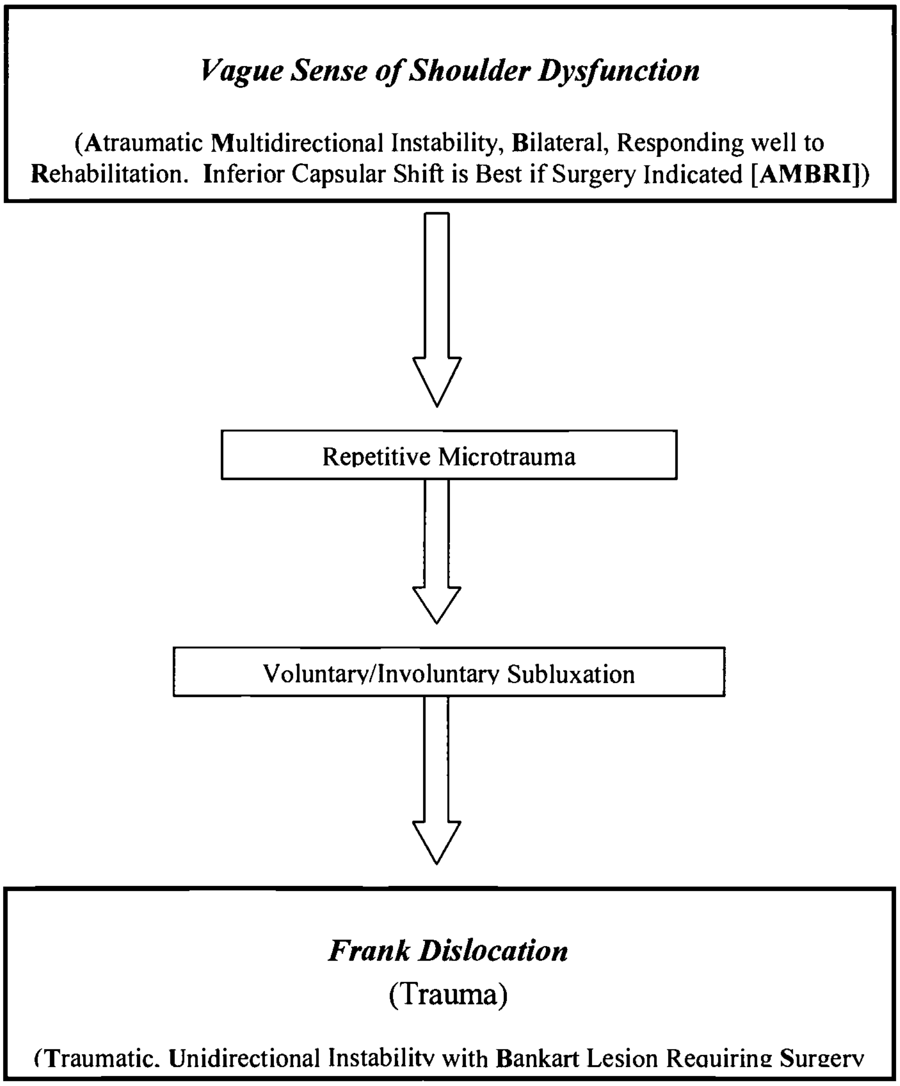
Classification of Shoulder Instability.

Because glenohumeral instability is represented by a continuum of injury including many varieties of instability, it is necessary to clarify what is meant by instability. Four major criteria are used to classify glenohumeral instability[5]: (a) degree of instability, i.e., dislocation, subluxation, or subtle instability; (b) frequency of instability (acute or chronic/recurrent); (c) origin of instability (traumatic, atraumatic/multidirectional, acquired/microtraumatic, or congenital); and 4) direction of instability (unidirectional, bidirectional, or multidirectional).

Shoulder instability can range from a vague sense of dysfunction to a traumatic episode of gross dislocation. Thomas and Matsen have been credited with introducing the acronyms TUBS and AMBRI[5], which describe the two ends of this spectrum of instability, i.e., traumatic and atraumatic instability. One end of the spectrum involves traumatic, unidirectional instability with an associated Bankart lesion that responds well to surgery (TUBS); the other end involves atraumatic, multidirectional instability in both shoulders that typically responds well to rehabilitation. In certain cases, an inferior capsular shift may be necessary (AMBRI) (Figure 1). Clinicians now recognize that shoulder instability involves a broad spectrum of pathoanatomy with a substantial amount of overlap between the previously discussed classifications. This classification system has been advocated as a more accurate representation of instability and a useful aid to clinicians in determining the origin and treatment of the majority of patients with shoulder instability.

FIGURE 1.
Spectrum of Shoulder Instability

(Adapted from Magee DJ & Reid DC: Shoulder Injuries. In: Zachazewsky JE, Magee DJ, Quillen WS, eds: Athletic Injuries and Rehabilitation. Philadelphia, W.B. Saunders Co., 1996.)



Vague Sense of Shoulder Dysfunction

(**A**traumatic **M**ultidirectional Instability, **B**ilateral, Responding well to **R**ehabilitation. **I**nferior Capsular Shift is Best if Surgery Indicated [**AMBRI**])

Repetitive Microtrauma

Voluntary/Involuntary Subluxation

Frank Dislocation
(Trauma)

(**T**raumatic, **U**nidirectional Instability with **B**ankart Lesion Requiring **S**urgery

Pathophysiology of Shoulder Instability.

Understanding of the pathophysiology of shoulder instability has improved over the past few decades, leading to enhanced methods of treatment. The cause of shoulder instability may vary depending on the origin of instability, i.e., traumatic, acquired, or functional instability. The primary abnormality associated with traumatic instability is thought to be detachment of the labrum from the glenoid rim with concurrent loss of capsuloligamentous tension.[15] In addition, damage may occur to the capsular structures themselves with a traumatic episode.

The Bankart lesion is classically described as detachment of the anteroinferior labrum with its attached IGHLC from the glenoid rim and scapular neck.[16] In 1938, Bankart described this as the "essential lesion" leading to recurrent anterior instability.[4,5,14,21] The Bankart lesion is a frequent result of traumatic anterior dislocation and is recognized as an important lesion to address when repairing the unstable shoulder either arthroscopically or with open stabilization.[5] Disruption of the attachment of the superior and middle glenohumeral ligaments onto the glenoid may also contribute to joint destabilization. Acquired instability refers to a chronic process and is often the result of repetitive microtrauma to the shoulder. Chronic submaximal loads may cause physiologic overload of the glenohumeral joint capsule leading to attenuation of the capsule. Finally, functional instability is being increasingly recognized as the result of excessive humeral head translation within the glenoid secondary to fatigue of the dynamic stabilizers of the glenohumeral joint.[17] This fatigue can lead to subtle subluxation of the humerus due to poor neuromuscular control. Diminished proprioceptive feedback has been implicated as the primary mechanism causing functional instability in the injured shoulder.[17]

SURGICAL TREATMENT OF ANTERIOR GLENOHUMERAL INSTABILITY (AGHI)

The primary objective of surgical repair for the treatment of AGHI is to prevent recurrent episodes of instability. Beginning with Hippocrates, surgeons used cautery to produce capsular scarring and tightening around the shoulder.[25] In the early twentieth century, a variety of surgical approaches were popularized to correct AGHI. Two types of surgical procedures developed: anatomic and nonanatomic repairs.[26] Anatomic repairs attempt to reestablish the pathologic anatomy, which is most often detachment of the anterior-inferior capsulolabral structures, i.e., the Bankart lesion. Anatomic procedures are often accompanied by a capsular shift to reduce redundant capsular tissue. Surgeons may choose to enhance a labral repair with either an anterior or inferior capsular shift procedure, or with the recently developed thermal capsulorrhaphy procedure. Nonanatomic procedures attempt to reinforce the anterior capsule either by tightening the capsule and subscapularis tendon; by transferring the tendon from the lesser to the greater tuberosity, i.e., Putti-Platt and Magnuson-Stack procedures, respectively; or by transecting the subscapularis, and transferring the coracoid process by attaching it to the anterior glenoid, i.e., Bristow procedure, thereby producing a "sling effect" on the humeral head. [25,26] These procedures were designed to limit excessive external rotation, which was believed to contribute to an increased incidence of recurrent instability.[5,27,28] While many nonanatomic approaches were initially popular, most became obsolete as long-term data revealed unacceptably high failure rates and significant loss of glenohumeral function due to restricted range of motion in external rotation.[3,4,25,26]

Recently, considerable advances have been made in open and arthroscopic repair of AGHI. Newer procedures have not attempted to merely correct instability at the expense of function but have addressed the specific pathologic lesions directly, i.e., Bankart lesion and redundant capsular volume. In both open and arthroscopic procedures, a balance exists between restoring glenohumeral stability and maintaining functional mobility. Open procedures typically tighten the joint capsule to achieve stability; however, overtightening the capsule may lead to pathologic limitation of shoulder motion. In contrast, arthroscopic procedures may allow for full glenohumeral ranges of motion; however, excessive motion may be responsible for the high failure rates often associated with arthroscopic repairs.[5]

A discussion of three prevalent surgical stabilization procedures used to address AGHI is presented here: open Bankart/capsular shift, arthroscopic Bankart, and thermal capsulorrhaphy. Surgical outcomes are provided for each procedure, with specific attention given to comparisons of open and arthroscopic stabilization.

Open Bankart/Capsular Shift Procedure.

The Bankart repair originally involved suturing the avulsed capsulolabral complex onto the anteroinferior glenoid through drill holes.[27] Subsequent techniques involved the use of staples (du Toit procedure), transglenoid sutures, and suture anchors as alternatives for labral repair, with each demonstrating improved success rates, respectively.[5,27,28] Because of the potential for multiple complications and high failure rates with both staple capsulorrhaphy and transglenoid sutures, suture anchors have become the method of choice for open capsulolabral reattachment.[27]

At its inception, a common result of the open Bankart procedure was limited external rotation. Initially, loss of external rotation was an acceptable outcome because it was thought that excessive external rotation was a risk factor for recurrent instability.[27] However, Rowe and coworkers[29] have shown that complete external range of motion was not associated with an increased incidence of recurrence, as only 2% of their patients with full range of motion suffered recurrent dislocation. Thus, a loss of external rotation after Bankart repair is no longer considered a necessary consequence. Newer procedures have been developed that prevent AGHI by addressing both the Bankart lesion and any capsular redundancy, while simultaneously increasing postsurgical range of motion. A variety of procedures have been described in the literature including: an inferior capsular shift originated by Neer and Foster[28], an anterior capsulolabral reconstruction by Jobe et al[14], and a T-plasty modification of the Bankart procedure credited to Altcheck and coworkers.[28,33] Each of these procedures involves a capsulotomy (L. capsula, "capsule", + G. tome, "a cutting"), which involves making a T-shaped capsular incision into the joint capsule, creating an inferior and superior flap.[14,17,18,28,33] The inferior flap of the capsule is then shifted superiorly and/or laterally, while the superior flap is advanced inferiorly and/or medially and sutured over the inferior flap. Procedures such as the anterior capsulolabral reconstruction and the T-plasty modified Bankart employ this technique to address both capsular redundancy and a labral lesion, if one is present.

Recently, considerable progress has been made in the ability of surgeons to repair Bankart/capsular lesions arthroscopically. Arthroscopic procedures could potentially lead to more accurate identification of intra-articular pathology, quicker repairs, less morbidity, faster recovery, less postoperative pain, fewer postoperative complications, and possibly greater returns in postoperative motion. [4,5,8,11,21,27]

Arthroscopic Bankart Procedures

Arthroscopic Bankart repair has become increasingly popular as a method for treating AGHI. This is due primarily to the belief that it is a less morbid alternative to open repair and it allows for better postoperative motion and function.[4,5,21] However, arthroscopic Bankart repairs have not had consistently successful outcomes. In general, failure rates following arthroscopic Bankart repair have ranged from 5 to 60%.[21] Earliest attempts at arthroscopy involved staple capsulorrhaphy—a single-point fixation of the Bankart lesion to advance it superiorly and medially.[5,8] Also, similar to open procedures, transglenoid sutures have been used to attach the labrum to the scapular neck through the use of a transglenoid drill hole.[5,8] However, these techniques resulted in an array of complications and failure rates as high as 50%.[5] One explanation for the high failure rates may be that the early procedures simply reattached the labrum without properly restoring capsuloligamentous tension in the inferior glenohumeral ligament complex.[17,23,24,26] These procedures have subsequently been replaced by newer techniques using bioabsorbable implants and suture anchors.[4,5,6,9,21] Reports of decreased failure rates have resulted with the use of these techniques because they are able to address both the Bankart lesion and capsular laxity that is often present with AGHI.[5] Clinical data are lacking regarding the use of suture anchors because the technique is relatively new. However, with the advances in arthroscopy today, supplementing arthroscopic capsular techniques with the use of suture anchors will likely lead to improved outcomes, i.e., decreased recurrence rates, in future studies.[5,21] The arthroscopic suture anchor technique may hold the most promise because it most closely resembles the open Bankart procedure.[21]

Thermal Capsulorrhaphy Procedure

Recently, the use of thermal energy has been introduced in arthroscopic procedures to decrease shoulder capsular redundancy and to reduce overall joint volume.[1,2,5,8,21] Thermal capsulorrhaphy (TC) procedures utilize either laser or radiofrequency energy to heat shoulder capsular tissue, causing significant collagen shrinkage.[30] A temperature "window" (65° to 75°C) has been identified in which collagen tissue may be effectively heated to create optimal tissue shrinkage and increase shoulder stability.[12] With this technique, it is important that tissues are not overheated, and thus overshrunk, because the mechanical properties (joint stiffness) of collagen tissue have been shown to decrease with increasing shrinkage.[1,2]

Initial procedures involved the use of the holmium:yttrium-aluminum-garnet (HO:YAG) laser to shrink the shoulder capsule.[8] A disadvantage of the HO:YAG is that it contains no inherent feedback mechanism which gauges shoulder tissue temperature. Thus, the HO:YAG may overheat collagen tissue if applied incorrectly or for extended periods of time. A recent device using radiofrequency energy has been developed (ETAC/Oratec Interventions Inc., Mountain View, California) which is capable of displaying tissue temperature within the glenohumeral capsule, enabling the surgeon to reach and maintain an ideal temperature for collagen shrinkage.[8] In addition, the decreased cost and decreased safety concerns associated with the radiofrequency device may make it a preferred instrument for thermal capsular procedures.[8] The beneficial effects of thermal capsulorrhaphy using the radiofrequency device are that it allows a direct, minimally invasive technique to treat redundant capsular tissue, the entire joint circumference can be treated, and the procedure can be accomplished in a short time with minimal cost.[8]

A preliminary study by Fanton has yielded encouraging results using thermal energy to increase joint stability.[8] However, studies have identified significant harmful effects to collagen structures following thermal repair.[12,13] The application of both laser and radiofrequency energy can cause substantial collagen denaturation.[12,13,30] Animal studies have shown that thermal shrinkage has an initial deleterious effect on the mechanical, histological, and biochemical properties of collagen tissue.[12,13] One study demonstrated that while radiofrequency energy altered the stiffness of capsular tissue, the treated tissue began to approach normal biomechanical properties (stiffness) at 6-12 following surgery.[35] Thus, it appears that thermal energy initially damages collagen tissue; however, studies in animal models have shown a steady return to near normal collagen structure during tissue remodeling. For this reason, patients are typically immobilized for longer periods of time following thermal capsulorrhaphy versus other arthroscopic and open stabilization procedures.

Results of Open and Arthroscopic Stabilization

Studies reporting outcomes of both open and arthroscopic procedures typically report three postoperative measures: ROM loss (particularly external rotation), recurrent subluxation /instability, and functional status (ability to return to previous sport or activity). Direct comparison of functional outcomes between open and arthroscopic stabilization techniques is often difficult because of differences in outcome scales used to measure postoperative results, varying definitions of "failure rate", and a variety of operative techniques used to treat a variety of glenohumeral pathology.

A common way of defining success after shoulder stabilization is by the rate of recurrent instability, with failure rates varying according to the techniques performed. Recurrences following open procedures generally are less than 10%[5], while failures following arthroscopic procedures vary between 3% and 33% for staple capsulorrhaphy[21] and 0% and 21% following application of a bioabsorbable tac[6] (the Suretac, Acufex Microsurgical, Norwood, MA).

Open Bankart/Capsular Shift Results. The medical literature is abundant with results following open stabilization procedures (Table 2). Failure rates typically range from 1% to 10%. Bigliani et al.[3] reported that 59 of 63 patients were rated excellent or good following an inferior capsular shift procedure, and 58 returned to sport participation. Average external rotation loss was 7°, and two patients redislocated after surgery. They concluded that inferior capsular shift is a reliable, consistent procedure for treating AGHI in the athletic population. However, return to high-level activities has had less successful outcomes following open stabilization. Jobe et al.[14] found that 50% of skilled pitchers returned to pre-injury levels of activity after anterior capsulolabral reconstruction, including 38% of professional pitchers. Only 1 pitcher was still competing after 2 years follow-up. Montgomery and Jobe[4] reported improved success rates with a modified capsulotomy and the use of suture anchors. In their study, 81% of pitchers were able to compete at their preoperative levels following the modified stabilization procedure (Table 2).

TABLE 2.

Outcomes of the Open Bankart/Capsular Shift Procedure

Study[ref]	*Procedure*	*No. of Pts.*	*Mean F/U (Yrs)*	*Ave ROM Deficit (ER)*	*% return to previous act.*	*Results*	*Recurrent Instability*	*Miscellaneous*
Gill et al, 1997[10]	*Bankart*	*56*	*11.9*	*-12°*	*98%*	*93% excellent or good*	*5%*	**Modified SR system, emphasis on pain-free functional motion*
Montgomery & Jobe, 1994[19]	*ACLR*[a]	*25*	*2*	*-1°*	*81%*	*96% excellent or good*	*4%*	*Modified Rowe scale*
Bigliani et al, 1994[3]	*AICS*[b]	*63*	*4.0*	*-7°*	*92%*	*94% excellent or good*	*3%*	*Did not report measurement scale*
Takeda *et al*, 1998[32]	*TPMB*[c]	*25*	*5.5*	----	*88%*	*100% excellent or good*	*0*	*Rowe scale*
Jobe et al, 1991[14]	*ACLR*[a]	*25*	*3.3*	*-3*	*72%*	*92% excellent or good*	*0*	*Modified Rowe scale*

[a] Anterior capsulolabral reconstruction
[b] Anterior inferior capsular shift
[c] T-Plasty modified Bankart
* Objective and subjective (patient satisfaction) measures were reported in this study.

Arthroscopic Bankart Results. As previously stated, arthroscopic procedures have historically yielded higher failure rates than open procedures for treating AGHI. However, current technology makes it easier to virtually duplicate open techniques with the arthroscope while reducing failure rates.[21] Gartsman et al.[9] reported on 53 patients undergoing arthroscopic Bankart repair combined with capsular retensioning. At mean follow-up of 3 years, 92% of the patients reported excellent or good postoperative results, and 89% were able to return to their previous level of activity. Four patients (7%) reported recurrent instability following surgery (two reported recurrent dislocations and one reported recurrent subluxation). Gartsman et al.[9] concluded that arthroscopic techniques are equivalent to open repair. The authors cited that the improved rate of success may have been due to the supplementation with thermal capsulorrhaphy in 91% of the surgical repairs to restore tensioning within the capsule.

Cole et al.[5] studied 37 patients after arthroscopic Bankart repair using absorbable implants. They found a 16% rate of recurrent instability, with 76% of patients demonstrating excellent or good results and able to return to previous activity with minor limitations. Cole et al. is one of only a few studies to directly compare results from arthroscopic stabilization with open techniques (Table 3). They conclude that arthroscopic Bankart repair and open capsular shift achieve similarly high success rates and patient satisfaction when selection criteria are determined on the basis of pathological findings.

TABLE 3.
Comparison of Results of Open and Arthroscopic Stabilization

Variable	Arthroscopy Group	Open-Repair Group
No. of patients	37	22
Recurrent dislocation or subluxation	6 (16%)	2 (9%)
Unsatisfactory result	9 (24%)	4 (18%)
Reoperation	2 (5%)	1 (5%)
Mean Rowe score	83	82
Excellent	23 (62%)	13 (59%)
Good	5 (14%)	4 (18%)
Fair	7 (19%)	5 (23%)
Poor	2 (5%)	0
ROM deficit in external rotation	-9 ± 12	-11 ± 10
Patient satisfied	84%	91%
Return to sport	17 (46%)	11 (50%)
Mild limitations	11 (30%)	6 (27%)

(From Cole BJ, L'Insalata J, Irrgang J, et al: Comparison of arthroscopic and open anterior shoulder stabilization. *J Bone Jt Surg* 82A(8):1108-1114, 2000.)

Thermal Capsulorrhaphy Results. Although thermal capsulorrhaphy (TC) is being used increasingly in clinical practice, there is a shortage of data concerning the long-term effects of thermal energy applied to the glenohumeral joint capsule. Recently, in unpublished data, Myers et al.[20] found that proprioception was restored following TC, as evidenced by normalized joint position sensibility; however, the average follow-up time in their study was limited to 12 months. Ellenbecker and Matallino[7] utilized a Cybex 6000 isokinetic dynamometer to measure rotator cuff strength and range of motion at 12 weeks following TC. External rotation strength was symmetric or greater in the injured versus the uninjured shoulder, while mild deficits (4%) were noted in internal rotation strength at 90°/sec. No significant differences were demonstrated between the operative and nonoperative shoulders in ER/IR strength ratios. Further, average deficits in external rotation range of motion were 13.1°. However, the authors cite that these deficits compare favorably with range of motion deficits at similar postoperative time intervals (12 weeks) following open and arthroscopic Bankart stabilization. Using a cadaveric model, Selecky et al.[31] demonstrated that the strength (based on load-to-failure measures) of the inferior glenohumeral ligament complex was not compromised following TC with a laser protocol. The lased specimens actually demonstrated a greater yield strain before the onset of plastic deformation, suggesting the specimens treated with TC were able to sustain greater stretch loads before failing. To date, no studies have been published which address longer-term (>2 years) effects of TC on shoulder proprioception, strength, and overall joint function in the unstable shoulder.

In summary, although some studies have shown that thermal capsulorrhaphy is an effective arthroscopic procedure for enhancing joint stability,[4,7,20,] the medical community currently considers it experimental.[1,21] This is primarily because long-term data do not exist on the effects of thermal energy applied to collagen tissue. Before considering the procedure to be a long-term success, specific studies are needed that address long-term functional outcomes after application of thermal energy to the unstable shoulder.

Summary of Arthroscopic and Open Stabilization Results. Open stabilization of the unstable shoulder is a versatile procedure capable of addressing a variety of lesions and capsular laxities. Open procedures generally have high success rates in terms of limiting recurrent instability. However, the results in terms of return to high-level activity have been less promising with open repair.[4] Also, open procedures may be associated with increased loss of motion in the repaired shoulder. In comparison, success rates for arthroscopic stabilization have varied widely, with early results demonstrating significantly higher recurrence rates than open stabilization. Current arthroscopic technology, i.e., suture anchor techniques combined with thermal capsulorrhaphy, may make it possible to duplicate success rates seen in open stabilization.[21] However, arthroscopic stabilization will continue to be held against the "gold standard" of open stabilization until arthroscopy can meet certain requirements: the success and failure rates must be comparable to open procedures, the results must be repeatable, and the techniques must be versatile and able to address multiple lesions.[5]

PATHOLOGY-BASED PROCEDURE SELECTION

Since a significant body of knowledge currently exists concerning objective and subjective outcomes following both open and arthroscopic stabilization, it is becoming more evident how the clinician should apply these findings toward the treatment of individuals with shoulder instability. Indeed, the value of functional outcomes lies in their usefulness for determining the ideal method of treatment for each individual patient with an unstable shoulder. Perhaps the most important factor determining the success rate of a particular stabilization procedure is the consideration of the pathoanatomy involved with each case.[4-6,11,21,34,36] A detailed history and physical examination; information concerning the onset, duration and frequency of instability; determination of either traumatic instability or under volitional control; imaging findings (plain x-ray, MRI, arthrography, CT-scan); examination under anesthesia; and arthroscopic evaluation are important components of a thorough approach toward understanding the cause of instability. These tools are essential for evaluating AGHI, for confirming the suspected pathology, and for determining whether an individual is a candidate for either open or arthroscopic stabilization.[4-6]

Considering the spectrum of instability previously discussed (Figure 1), the most straightforward decisions based on the pathoanatomy can be made more easily for individuals on either end of the spectrum of instability, i.e., TUBS versus AMBRI. Less clear-cut are the decisions concerning the best method of stabilization for individuals in the middle of the spectrum.

Cole and Warner[4] developed profiles for patients with traumatic instability who are considered ideal candidates for either open or arthroscopic stabilization. In addition, they identify patients who may benefit from thermal capsulorrhaphy. In general, patients who primarily want stability, sometimes at the expense of loss of motion (particularly in external rotation) should most likely be treated with open stabilization. An ideal candidate for open stabilization includes a contact athlete with atraumatic instability, poor anterior ligamentous stability, and a bony lesion, e.g., Hill-Sachs lesion. A rotator cuff tear, generalized ligamentous laxity, and the lack of a Bankart lesion are also considered to be indications for open stabilization.[4] Conversely, patients who desire a less invasive approach, with less surgical morbidity should most likely be treated arthroscopically. An excellent candidate for arthroscopy is most likely a high performance athlete involved with overhead activities. However, the ideal arthroscopy candidate, according to Cole and Warner[5], may be the noncontact athlete or sedentary individual with traumatic unidirectional instability, an isolated Bankart lesion, a sufficient IGHLC, without significant capsular laxity or substantial internal derangement of the joint.[4,5] Although insufficient data exist concerning the use of thermal capsulorrhaphy as an adjunct to arthroscopy, Cole and Warner suggested that thermal capsulorrhaphy is useful for treating the patient with capsular laxity combined with a Bankart lesion. They recommended that glenohumeral capsular laxity be addressed after the Bankart lesion has been stabilized.[4,5]

To summarize, in deciding what procedure is ideal for each individual with an unstable shoulder, the clinician relies on patient evaluation, radiographic findings, examination by a physician under anesthesia, and a physician's findings during arthroscopy. A useful algorithm has been developed that may prove helpful and reassuring both to the clinician, i.e., the certified athletic trainer or physical therapist, working with a patient with shoulder instability, and to the patient making a decision to have surgery and what procedure is most suitable.

CONCLUSION

Surgical management of anterior glenohumeral instability remains a challenge. The most appropriate treatment options for a patient with an unstable shoulder depends on a variety of factors including the degree, frequency, origin and direction of instability; the specific pathoanatomy involved; results from the physical examination, examination under anesthesia, and with arthroscopy; success rates of open and arthroscopic surgical procedures; as well as patient preference and the surgeon's experience performing the particular procedure. Viewing AGHI as a spectrum of injury allows for more accurate decision-making concerning surgical treatment approaches for the unstable shoulder. Also, current literature on outcomes following each procedure has allowed the judicious selection of appropriate procedures, and the establishment of patient profiles that may be helpful in identifying suitable candidates for each stabilization technique.

Considerable advances have been made in both open and arthroscopic stabilization of AGHI. Although arthroscopic approaches originally resulted in high failure rates, a growing body of evidence is establishing that, if one selects patients for arthroscopic Bankart or open capsular shift on the basis of pathoanatomic findings, the results between the two procedures are comparable and may even be equivalent.[4,5,21]

With innovative techniques such as thermal capsulorrhaphy, and improved instrumentation, coexisting pathology can now be repaired arthroscopically. Further, these techniques are becoming popular because they are associated with decreased surgical morbidity, decreased surgical time, and lower levels of post-surgical pain. However, the careful use of these techniques is advisable until long-term data are generated concerning their effects on shoulder strength, motion, and overall function.

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SENSORIMOTOR CONTRIBUTIONS TO GLENOHUMERAL JOINT STABILITY

Implications for the Unstable Shoulder

INTRODUCTION

Glenohumeral joint instability is a common and problematic phenomenon in the physically-active community. Over the past 20 years, significant progress has been made toward the assessment, classification, and management of glenohumeral instability. An improved understanding of the static and dynamic structures contributing to glenohumeral joint stability has resulted in a more accurate recognition of instability as a continuum of injury. In addition, advances in conservative and surgical management of instability have resulted in improved outcomes for the unstable shoulder. Innovative arthroscopic surgical techniques have recently been developed that are capable of matching the success rates of traditional open arthrotomy in stabilizing the glenohumeral joint.[1] However, less progress has been made in understanding the complex contributions of neurological mechanisms such as proprioception and neuromuscular control to glenohumeral joint stability. The glenohumeral joint may rely more heavily on proprioception than any other human joint. Thus, deficits in proprioception have been implicated in a large number of injuries that occur under seemingly innocuous conditions such as the unstable shoulder which repeatedly subluxates or dislocates.

Proprioceptive research at the glenohumeral joint has been relatively untouched until the last decade; thus little is currently known concerning the contributions of proprioception to shoulder stability. Proprioception is thought to act as a kind of injury prophylaxis by means of a neurofeedback loop, which serves to enhance dynamic shoulder stability. Although the exact neural mechanisms involved in this loop are not currently known, any disruption of the proprioceptive mechanism is thought to contribute to functional instability at the shoulder.

The aim of this review is to provide an overview of the somatosensory and motor systems—including peripheral afferent mechanoreceptors, supraspinal tracts, the CNS, and efferent pathways—and their roles in contributing to proprioception and stability at the glenohumeral joint. The effects of a neuromuscular reflex arc on the dynamic stability of the shoulder will also be discussed.

SOMATOSENSATION & PROPRIOCEPTION

Beard et al.[2] have described the contemporary dilemma concerning proprioception, stating that there is no universally accepted definition among the scientific community. Sherrington is credited with the original description of proprioception in 1906.[3] However, much debate currently exists over how to interpret Sherrington's initial ideas. When measuring proprioception clinically, most researchers distinguish between static and dynamic sensibility. Static proprioception is commonly defined as joint position sense (JPS) or the perception of the orientation of body segments with respect to each other; whereas dynamic proprioception may be classified as kinesthesia—the sense of the rate and direction of movement at a given joint.[4,5] A variety of factors influence proprioception including vestibular inputs, automatic postural responses, visual information, and reflexes (such as the vestibulo-ocular reflex which stabilizes the eyes when the head moves).[16,17,24] Combining the current information concerning proprioception, the definition may include all neural inputs from joints, muscles, tendons, and skin that are projected up to the CNS for processing.[3,18] (Fig. 1)

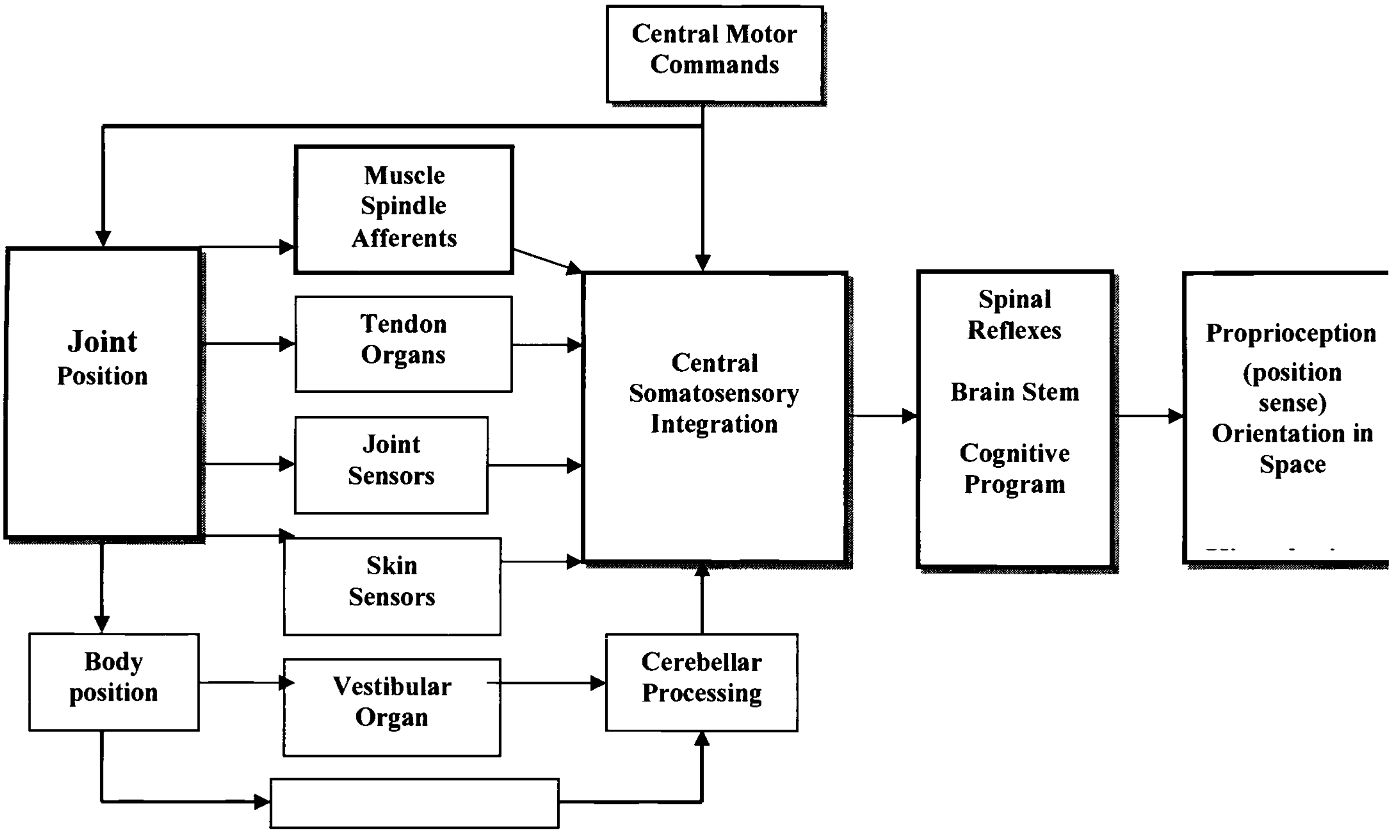

Fig. 1 Factors that Influence Proprioception.
(Modified from Jerosch J, Prymka M: Proprioception and joint stability. Knee Surg, Sports Traumatol, Arthrosc 4:171-179, 1996.)

This definition describes proprioception specifically as the afferent pathway of the sensorimotor system—a term that has recently been adopted by a consortium of professionals[2] to represent a complex array of neural mechanisms including the acquisition of a sensory stimulus, the conversion of the stimulus into a neural signal, the transmission of the signal to the CNS, the integration of a signal by the components of the CNS, and the resulting motor response which activates muscles necessary for movement and joint stability. While many aspects of proprioception are becoming more lucid, there are substantial facets of the sensorimotor system that are relatively unknown.

Particularly unclear is the influence of the CNS on joint proprioception. This review will discuss each of the processes of the sensorimotor system—including the afferent pathways, sensory integration, and efferent pathways—involved with coordinated movement and joint stability.

Mechanoreception: capsuloligamentous receptors.

Somatosensation is initiated by sensory receptors that detect mechanical stimuli and convert these stimuli to neural signals. Joint mechanoreceptors have been classified into four types based on their activation characteristics.[2,5,18] Ruffini endings demonstrate a low-threshold to mechanical stress, are slowly adapting, and have been found mainly within capsuloligamentous structures, and the skin.[2,5] Ruffini endings are thought to signal static joint position, intra-articular pressure, and velocity of joint rotation. [2,5,19] Pacinian corpuscles demonstrate a low-threshold to mechanical stress but are rapid adaptors and are present in deeper layers of the joint capsuloligamentous structures, muscular fascia, and skin.[2,5] These receptors are silent during static conditions and during rotation of a joint at a constant velocity; however, they are very sensitive to joint acceleration and deceleration, providing dynamic mechanoreception at a joint.[2] Golgi endings demonstrate a high-threshold to mechanical stress and are slowly adapting tension sensors which assist with joint position sense (JPS) during volitional muscle activity and passive muscle-tendon stretching, much like muscle spindle afferent (MSA) receptors.[5] These receptors are completely inactive in immobile joints and demonstrate increased activity at extremes of a joint's normal range of motion.[2] Free nerve endings are widely distributed throughout joint capsule layers and articular structures and are generally considered pain receptors; however, they have also been shown to contribute to joint proprioception.[2,5] Free nerve endings remain dormant during normal joint conditions but are activated in the presence of mechanical deformation and certain chemical substances (e.g. inflammatory mediators: serotonin, histamine, prostaglandins, bradykinin).[2] The role of these capsuloligamentous mechanoreceptors is to acquire mechanical or chemical information that are converted to a neural signal and transmitted to the central nervous system (CNS), enabling progressive motor responses from the CNS.[2,5,18]

Mechanoreception: musculotendinous receptors.

In addition to capsuloligamentous mechanoreceptors, a joint receives proprioceptive input from musculotendinous receptors in close proximity to the joint. Two mechanoreceptors are located within musculotendinous structures of human joints: muscle spindle afferent receptors (MSAs) and golgi tendon organs (GTOs). MSAs are located in the fleshy component of muscle and primarily signal changes in length of muscle.[20] The CNS utilizes MSAs to sense relative positions of the body's segments. In addition, the CNS and the gamma motoneuron system play important roles in varying the bias and sensitivity of these receptors.[5,20,28]

GTOs are located at the muscle-tendon junction and are arranged in series with the skeletal muscle fibers.[20] GTOs are most sensitive to changes in muscle tension and are readily activated with normal movements. These receptors continuously provide the CNS with sensory information by monitoring the force in a contracting muscle.[20]

Mechanoreceptors in the glenohumeral joint.

Research studies involving the presence of mechanoreceptors in human joints has focused primarily on lower extremity joints such as the knee and ankle. However, increased attention has recently been directed at determining the neural supply of the shoulder. Pacinian corpuscles have been shown to occur predominantly in the glenohumeral joint capsule and may be more common in the shoulder joint than the knee.[5] Using human cadavers, Vangsness et al.[21] reported Pacinian corpuscles in the glenohumeral ligaments, and identified an abundance of Ruffini endings in the coracoacromial and acromioclavicular ligaments. Vangsness et al.[21] proposed that the vast range of motion available at the glenohumeral joint necessitated an expansive position sensibility from slowly adapting proprioceptors (primarily Ruffini endings) located in capsuloligamentous structures. Vangsness also found free nerve endings in the periphery of the glenoid labrum. Jerosch et al.[22] demonstrated histological evidence of Pacinian corpuscles distinctly in the glenohumeral ligaments, directly beneath the synovial membrane, and added that these proprioceptors were "not part of the rotator cuff tendons" (pg 154).

Musculotendinous mechanoreceptors of the glenohumeral joint are located primarily within the insertions of the supraspinatus, infraspinatus, and pectoralis minor muscles, as well as within the origins of the biceps brachii, triceps brachii, coracobrachialis, and deltoid muscles.[5] Studies involving humans have previously demonstrated that muscle spindle density is established prior to birth and remains constant with aging.[5] A review of muscle spindle densities located within particular muscles has revealed that muscles that attach to the coracoid process, and those crossing the glenohumeral joint anteriorly, demonstrate higher densities of MSAs than do the rotator cuff muscles.[5] Muscles such as the coracobrachialis, pectoralis major, teres major, and latissimus dorsi may therefore contribute significantly to proprioception while the rotator cuff musculature may be less essential in providing proprioceptive information.[5]

FUNCTIONAL ORGANIZATION OF THE SOMATOSENSORY AND MOTOR SYSTEMS

In order to understand the neurological aspects of shoulder joint stability, it is first necessary to consider the interconnected networks of neurons, or circuits that are responsible for the perception of sensory information, how these perceptions are integrated by supraspinal structures, and how perceptions ultimately become motor actions. Specific receptors involved in proprioception and the specific mechanical/chemical stimuli to which they respond have previously been discussed. Discussed here are the major sensory pathways that carry information from these receptors to the cerebral cortex. Sensory pathways include peripheral receptors and the neurons that link the extremity (in our case, the shoulder) with the spinal cord, brain stem, thalamus, and cerebral cortex.[15]

Movement of the glenohumeral joint is perceived when a mechanoreceptor in the joint capsule senses an increase in the tension of its fibers, causing a discharged action potential.[23] The resulting signal is propagated to the spinal cord, up to the dorsal column nuclei of the thalamus, and then to areas of the cortex.[5,23,24] The specific pathways involved with signal propagation deserve more attention and are addressed here.

Sensory information processing: the ascending dorsal pathway.

Sensory neurons from the skin, muscles, fascia, and joints enter the dorsal aspect of the spinal cord from the limbs. These neurons are clustered together in the dorsal root ganglia within the vertebral column in close proximity to the spinal cord.[23] Sensory neurons are pseudounipolar—their bifurcated axons may terminate in skin, muscle or other tissue as specialized receptors, or may enter the spinal cord.[23] Once in the spinal cord sensory neurons may either terminate in the gray matter as part of a reflex loop, or may ascend to nuclei higher up the spinal cord and into the medulla.[23] Thus, two functional pathways exist for somatosensory information entering the spinal cord from the dorsal root ganglion. The local branches facilitate reflex actions that remain at the spinal cord level, whereas the ascending branches communicate with higher CNS centers to facilitate the perception of joint position, movement sensibility, or touch.[23]

In the spinal cord, the ascending axons are distributed in an orderly fashion, commonly referred to as somatotopy.[23] For example, axons that enter the cord in the lumbar region are assembled in the spinal column near the midline, while axons entering at the cervical level from the shoulder ascend at progressively more lateral positions within the cord. This orderly pattern is maintained throughout the spinal column.

The Thalamus: the link between receptors and cortex. The thalamus is the "discerning relay station" for the flow of somatosensory information to the neocortex.[23] The thalamus does not simply relay information to the neocortex, but conducts information processing, either preventing or enhancing information transmission to higher centers.[23,24] Specifically, somatosensory information from the dorsal root ganglia reaches the ventral posterior lateral nucleus of the thalamus, which conveys the information to the somatosensory cortex.

Somatosensory cortex. The cortex is organized somatotopically—all portions of the body are represented in the cortex according to their degree of neural innervation.[23] Thus, areas such as the fingers, mouth, and lips, which are highly innervated and convey a large amount of somatosensory information to the cortex, are represented by a much larger functional area of the cortex than areas such as the shoulder which have less neural innervation.[16] The somatosensory cortex has four areas, each containing a topographical map of the body. Through electrophysiological studies, an area ("Area 2") has been identified to which joint position and tactile information are relayed and combined.[23] Just as other components of the somatosensory system, the cortex is organized hierarchically. The processing of somatosensory information occurs in the unimodal association areas.[25] These areas then project to multimodal areas which combine information from a variety of sensory modalities.[25] Sensory systems also project to motor areas including the premotor cortex.[23] Thus, a close association is demonstrated between the somatosensory and motor functions of the cerebral cortex.

In summary, somatosensory information is processed in the CNS in stages. Processing begins in the dorsal root ganglia, ascends to the thalamus, to the somatosensory cortex, and finally to unimodal and multimodal association areas. Each of these processing stations incorporates information from neighboring receptors. The system also utilizes inhibitory neurons to execute coordinated movement, a process that will be discussed later in this paper.

Motor information processing: the descending lateral corticospinal pathway.

In contrast to the sensory systems, which transform mechanical stimuli into neural signals, motor systems transform neural signals into muscular contractions to invoke movement. In order to perform smooth actions, the motor system requires proprioceptive information from afferent pathways that provide the cortex with an internal representation of the body. Therefore, the basis of efficient movement depends on the effective interaction of the sensory and motor systems.

The forebrain, brain stem, and spinal cord. Motor systems, like sensory systems, are organized in a functional hierarchy. The forebrain, brain stem, and spinal cord are interconnected, allowing for each level to organize and control increasingly complex motor responses.[26] Also, a system of parallel processing allows for the performance of an extensive amount of tasks with speed and accuracy.[26]

The dorsolateral frontal cortex is the highest level of the motor systems and is associated with analyzing the purpose of a movement. The motor plan is generated from the interaction of the posterior parietal and premotor areas of the cortex, which are located in the frontal lobe.[25] The flow of information in the frontal lobe is essentially the reverse of the sensory systems. [25] Information is processed in the prefrontal cortex, then is relayed to the premotor cortex, which integrates sensory information about the position of the limb in space to designate the spatial qualities of the movement, i.e., the motor program.[25] The motor program is then activated by projections from the motor cortex. Neurons from the motor cortex fire primarily to produce specific movements around specific joints.[25]

The next level of the motor systems, the brain stem, receives input from the cerebral cortex and projects to the spinal cord. The medial descending system of the brain stem receives somatosensory information from the cortex and integrates it with visual and vestibular information to control posture.[26] The lateral descending system controls distal motor actions of the arm and hand.[26]

The spinal cord is the lowest level of the motor systems. It contains neural circuits that perform a variety of reflexes, automatic postural responses, and rhythmic automated movements such as walking.'[17,26] Spinal reflex circuitry is valuable to motor systems as they make use of these pathways, not only for reflexive actions, but also for more complex movements. Supraspinal signals act to modify these reflex pathways by the use of interneurons, which facilitate or inhibit effector muscles depending on the specific task.[26]

All motor commands eventually converge on motor neurons (the "final common pathway") which exit the spinal cord ventrally and innervate skeletal muscles.[2,20] The cerebral cortex directly controls these motor neurons in the spinal cord through two descending pathways: the ventral and lateral corticospinal tracts.[2] These pathways are direct and powerful routes by which the cerebral cortex affects the motor neurons that terminate at peripheral muscles.

The cerebellum and basal ganglia. In addition to the forebrain, brain stem, and spinal cord, the motor systems also use the cerebellum and basal ganglia to plan and execute movement.[26] Although the specific contributions of each structure is not currently known, the basal ganglia has been implicated in the selection of adaptive behavioral plans, and the cerebellum is likely involved in the timing and coordination of movements, particularly in learning new motor skills.[26]

To summarize, motor pathways include motor commands that control the muscular response to a perceived mechanical stimulus. Interconnected areas of the spinal cord, brain stem and cortex control successively more complex voluntary responses to somatosensory stimuli. Cortical motor areas receive information from peripheral sensory stimuli as well as prefrontal areas that integrate current information with previous experience. Motor areas of the cortex are aided by the cerebellum and basal ganglia in movement execution. In addition, the brain stem integrates spinal reflexes to produce automated responses to stimuli. These spinal reflexes are further examined here.

Spinal reflexes and joint stiffness.

In order to have an appreciation for the neural mechanisms that contribute to joint stability, it is necessary to first discuss the neural circuitry of a spinal reflex. The sensory stimuli that elicit spinal reflexes are perceived by previously discussed afferent mechanoreceptors in capsuloligamentous and musculotendinous structures in and around a joint. The neural circuitry necessary for spinal reflexes is contained entirely within the spinal cord; however, reflexes may be modified by supraspinal centers (brain stem nuclei, cerebellum, and motor cortex) in order to adapt to specific tasks.[2,20]

Reflexes may be either monosynaptic, such as the stretch reflex, or polysynaptic, such as the flexion withdrawal reflex. The monosynaptic pathway exhibited by the stretch reflex involves Ia afferent fibers from MSA's that convey a neural signal to two sets of motor neurons: alpha motoneurons that innervate the identical muscle from which they originate, and motoneurons that innervate synergist muscles. The Ia fibers also converge on Ia inhibitory interneurons to innervate antagonist muscles and act to inhibit these muscles.[20] The polysynaptic pathway exhibited by the withdrawal reflex utilizes divergent pathways in which the sensory signal activates muscles of the stimulated limb and inhibits antagonist muscles ("reciprocal inhibition"), while also stimulating contralateral agonist muscles to provide postural support while the limb is withdrawn ("crossed-extension reflex").[20] The basis of reciprocal inhibition is the action of the Ia inhibitory interneuron to suppress the activity of antagonist muscles when the agonists are acting.[20]

Another important function of spinal reflexes is the ability to stimulate and contract both agonists and antagonists at the same time. Such co-contraction is necessary at the glenohumeral joint under certain conditions. For example, in the cocking phase of throwing the shoulder is in a "position of vulnerability" to anterior translational forces. Muscular co-contraction of the agonists and antagonists acts to stabilize the glenohumeral joint in this position. Further, because both precision of movement and joint stabilization are necessary to complete a throw, the descending pathways of the CNS send both excitatory and inhibitory signals to the Ia inhibitory interneurons. By changing the balance of excitation and inhibition to these interneurons, the supraspinal centers can control joint stiffness by reducing reciprocal inhibition and enabling co-contraction.[20] Thus, supraspinal structures act to inhibit the Ia inhibitory interneuron, the process of disinhibition.[17] This action allows for dynamic glenohumeral joint stability.

IMPLICATIONS FOR THE GLENOHUMERAL JOINT

Armed with a working knowledge of the sensorimotor system and spinal reflex circuitry, we can now apply these neural concepts to the shoulder. The glenohumeral joint lacks osseous support that is characteristic of more stable "ball and socket" articulations such as the os coxae (hip) joint. The shoulder therefore compromises stability for mobility, and relies heavily on static (capsuloligamentous) and dynamic (musculotendinous) structures for joint stability. In order to accomplish full motion while maintaining optimum joint stability, the shoulder relies particularly heavily on a neuromuscular feedback loop which makes use of complex processes such as co-

contraction and alpha-gamma co-activation. The specific contributions of these processes to shoulder stability are discussed here.

Glenohumeral joint stability.

The "circle concept" of glenohumeral stability accurately explains the length and orientation changes that occur in capsuloligamentous structures with joint rotation.[5] The joint capsule consists of circularly-linked fibers that form a capsular cylinder. Glenohumeral rotation (particularly external rotation and abduction) causes increased tension in these spiral-shaped fibers, leading to capsular tightening and a stabilizing circular constriction of the humeral head, centering it into the glenoid.[5] This action has been likened to a "Chinese finger trap" [5]. With increased rotation, the sequential tightening of the capsule causes stimulation of mechanoreceptors.[5,19] As the end range of glenohumeral motion is reached, the greatest number of capsuloligamentous mechanoreceptors is activated. In contrast, during mid-ranges of motion, capsular mechanoreceptors are not active; however, musculotendinous afferents provide significant contributions to joint position and movement sense in these positions.[5] MSAs have been shown to actively trigger the glenohumeral musculature which provides reflexive stability to the joint.[18] As a result, a proprioceptive and stability alliance exists between static and dynamic stabilizers at varying ranges of glenohumeral joint motion.

Recently, numerous studies have analyzed glenohumeral joint position sense and kinesthesia in subjects with healthy shoulders,[6-9] with unstable shoulders,[10,11] after muscle fatigue,[12-14] and after lidocaine injection.[15] Using a feline model, Gaunche et al.[19] demonstrated the existence of a reflex arc from the glenohumeral joint capsule to several muscles crossing the joint. The authors cited the need for future studies to determine if this reflex arc also ascends from the spinal cord to higher supraspinal structures for perception and voluntary posture modification. Consequently, Tibone et al.[27] used an electrode probe to stimulate intra-articular glenohumeral structures (inferior and middle glenohumeral ligaments, subscapularis, biceps tendon, supraspinatus rotator cuff capsule, labrum, and humeral head) while patients were undergoing arthroscopy. Somatosensory cortical evoked potentials were simultaneously monitored through scalp electrodes. All intra-articular structures except the articular cartilage of the humeral head generated consistent waveforms. Thus, direct evidence was provided of an intact afferent electrical pathway originating in the glenohumeral joint structures and terminating in the cerebral cortex. The authors did not find significant differences in the reflex-arc between subjects with healthy and unstable shoulders.

In contrast, Lephart et al.[10] have demonstrated impaired proprioception in patients with unstable shoulders. Using threshold to detection of passive motion (TTDPM: assessing *kinesthesia*), and reproduction of passive positioning (RPP-assessing *joint position sense*) these authors demonstrated deficits in TTDPM and an increased error in RPP with injured subjects. Tibone et al.[27] suggest that Lephart's findings may be either the result of gross injury to neural elements within the reflex pathway, or that these elements were simply not being activated properly. Further, Lephart et al. demonstrated that injured subjects' proprioceptive capabilities improved significantly following a capsular-tensioning surgical procedure. These findings suggest that an attenuated joint capsule leads to inefficient mechanoreceptor firing rates, and that surgery may correct this deficiency. When taken together, the findings of Lephart et al. and Tibone et al. suggest that the neurologic elements within the unstable glenohumeral joint are not damaged in a gross fashion with injury, but rather the reflex pathway remains intact and is not being activated effectively.

An explanation for the diminished firing may lie in the relationship of alpha-gamma motoneurons and their coactivation. Nyland et al.[5] and others[2] state that normal functioning of joint mechanoreceptors is vital to joint stability because these afferents modulate protective motor responses. For example, stimulation of MSAs causes reflexive muscular contraction of agonist muscles via alpha motoneurons. Normal joint afference involves the constant modulation of the sensitivity of MSAs by gamma motoneurons and by the CNS.[2,5] Further, activation of musculotendinous mechanoreceptors encourages gamma motoneuron activation of both agonist and antagonist muscles acting at the shoulder joint. As previously discussed, this co-contraction occurs because of CNS action at the inhibitory interneuron, thus creating synergistic stabilization of the joint.

Johansson et al.[28] reviewed current data to explain that mechanoreceptors may be more important in stimulating the gamma muscle spindle system than the alpha motoneuron system. Data revealed that mechanoreceptors evoked only weak effects in alpha motoneurons, while they frequently caused powerful gamma effects. Johansson et al. describe the effects of mechanoreceptors on the gamma system as being so potent that stretching of a ligament at modest loads may induce major response from MSAs. In response, activity in the MSAs modifies muscle stiffness, while capsular mechanoreceptors, via the gamma system, may participate in modulation and programming of the muscle stiffness at the joint.[28]

However, as demonstrated by Lephart et al.[10] this close communication between the afferent and efferent systems may be diminished with injury to capsuloligamentous or musculotendinous structures acting at the shoulder. The most credible explanation for this deficit is that injury to the glenohumeral joint capsule/ligaments may result in an inability of the mechanoreceptors (primarily Ruffini endings and Pacinian corpuscles) to sense motion, particularly at end range, which results in a failure to signal alpha motoneurons that stimulate and recruit the dynamic stabilizers of the joint.[1] Vangsness et al.[21] reinforce this concept by stating that functional instability of a joint may result "from the decrease in intrinsic protective muscular tone and coordination that the joint derives from its afferent proprioceptive reflex" (pg. 183). Further, Jerosch et al.[22] propose that detachment of the anterior labrum may contribute to permanent glenohumeral instability. The Bankart lesion may prevent capsular tissue from stretching which results in loss of the afferent feedback function of glenohumeral ligaments. Additional studies are needed in this area to determine the exact mechanism causing this "functional instability".

Surgical considerations.

Successful surgical outcomes to correct glenohumeral instability require careful strategies to restore normal joint arthrokinematics without "overtightening" the capsuloligamentous structures. Lephart et al.[10] and others[1] have documented that surgical methods aimed at restoring normal capsular tensioning and re-establishing proper length-tension relationships may combat the problem of functional instability by preserving mechanoreceptors. However, the best type of capsular reconstruction for preserving proprioceptive structures remains elusive. In addition, the effects of innovative stabilization techniques such as arthroscopic thermal capsulorrhaphy and arthroscopic labral repair on glenohumeral proprioception and kinematics remain unknown. Clearly lacking are studies that examine patients pre- and postoperatively, over an extended follow-up period, to assess shoulder function following these procedures.

CONCLUSIONS

In summary, the glenohumeral joint utilizes the neural pathways of the sensorimotor system to accomplish stability of the joint while maintaining full range of motion. Current research indicates that proprioceptive mechanisms appear to contribute to glenohumeral joint stability by facilitating the alliance between static and dynamic stabilizers. The activation of mechanoreceptors in capsuloligamenoutous and musculotendinous structures results in a reflex-mediated protective muscular response that contributes substantially to glenohumeral stability. This neuromuscular feedback loop is ultimately under the control of upper levels of the CNS hierarchy, which modulate and control the sensitivity of its components. Injury to this protective reflex arc is thought to contribute to glenohumeral instability; however further studies are necessary to determine the exact neural mechanisms responsible for recurrent instability.

In order to gain a more accurate perspective on the unstable shoulder, neural patterns of the glenohumeral capsule need to be further delineated. In addition, it appears that innovative surgical techniques which restore proper anatomical length-tension relationships may restore proprioceptive function and increase glenohumeral joint stability. Further studies examining the effects of surgical techniques on shoulder proprioception are needed. Particularly, the effects of thermal agents used in capsular shrinkage procedures deserve attention.

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