BIOMECHANICAL EVALUATION OF GLENOHUMERAL JOINT STABILIZING

MUSCLES DURING PROVOCATIVE TESTS DESIGNED TO DIAGNOSE

SUPERIOR LABRUM ANTERIOR-POSTERIOR LESIONS

by

Vanessa J. C. Wood

A thesis

submitted in partial fulfillment

of the requirements for the degree of

Master of Science in Mechanical Engineering

Boise State University

Summer 2009

BOISE STATE UNIVERSITY GRADUATE COLLEGE

DEFENSE COMMITTEE AND FINAL READING APPROVALS

of the thesis submitted by

Vanessa J.C. Wood

Thesis Title: Evaluation of Glenohumeral Joint Stabilizing Muscles During Provocative Tests Designed to Diagnose Superior Labrum Anterior-Posterior Lesions

Date of Final Oral Examination: 09 June 2009

The following individuals read and discussed the thesis submitted by student Vanessa J.C. Wood, and they evaluated her presentation and response to questions during the final oral examination. They found that the student passed the final oral examination.

Michelle B. Sabick, Ph.D.   Chair, Supervisory Committee

Ron P. Pfeiffer, Ph.D.   Member, Supervisory Committee

Kotaro Sasaki, Ph.D.   Member, Supervisory Committee

The final reading approval of the thesis was granted by Michelle B. Sabick, Ph.D., Chair of the Supervisory Committee. The thesis was approved for the Graduate College by John R. Pelton, Ph.D., Dean of the Graduate College.

ACKNOWLEDGEMENTS

At this time I would like to express my profound gratitude to a handful of people who were instrumental in my success at Boise State University and the completion of my degree. For the length of my studies at Boise State University, I have been extremely fortunate to receive extensive academic and financial support.   My accomplishments would have been impossible without the guidance, patience, and generosity of these individuals.

- Thesis Committee
    - Dr. Michelle Sabick, Advisor
    - Dr. Ronald Pfeiffer
    - Dr. Kotaro Sasaki

I would also like to thank the following individuals for their help and support in the completion of this project specifically. Without them, this study would not have been possible.

- Center for Orthopaedic and Biomechanics Research
    - Seth Kuhlman
    - Jason Christensen
- Intermountain Orthopaedic
    - Dr. Michael Curtin
    - Dr. Kurt Nilsson
    - Dr. Kevin Shea

Furthermore I must express my gratitude for the opportunities I received here at Boise State as a Graduate Research Assistant for both Dr. Michelle B. Sabick (2007-2009) and Dr. John F. Gardner (2006-2007), without their support I clearly would not have been able to pursue graduate studies or academic research.

ABSTRACT

**Biomechanical Evaluation of Glenohumeral Joint Stabilizing Muscles during
Provocative Tests Designed to Diagnose SLAP Lesions**

Vanessa Wood

Despite considerable advances in the understanding of glenohumeral (GH) biomechanics and glenoid labral pathologies, arthroscopy remains the only definitive means of Superior Labrum Anterior-Posterior (SLAP) lesion diagnosis. Unfortunately, natural GH anatomic variants limit the reliability of radiography. Accurate clinical diagnostic techniques would be advantageous due to the invasiveness, patient risk, and financial cost associated with arthroscopy. Twenty provocative tests designed to elicit labral symptoms as a diagnostic sign have shown promising accuracy by their respective original authors, but later studies generally fail to reproduce those findings. The purpose of this study was to compare the behavior of GH joint stabilizing muscles in promising tests. Electromyography (EMG) was used to characterize the activation of GH joint stabilizing muscles, with particular interest in the Long Head Biceps Brachii (LHBB) behavior, as activation of the LHBB and subsequent tension in the biceps tendon should illicit labral symptoms in SLAP lesion patients.

Volunteers (n=21) with no history of shoulder pathology were recruited for this study. The tests analyzed were Active Compression, Speed's, Pronated Load, Biceps Load I (Bicep I), Biceps Load II (Bicep II), Resisted Supination External Rotation (RSER), and Yergason's. Test modifications that allowed the use of the Biodex System improved reproducibility. EMG was used to record activity for GH muscles: the LHBB, short head of the biceps brachii, anterior deltoid, pectoralis major, latissimus dorsi, infraspinatus, and supraspinatus. An indwelling electrode was used to monitor supraspinatus activity, and the remaining muscles utilized surface electrodes. EMG data were recorded at 1250 Hz and filtered with custom MATLAB software. Muscle activity for each test was characterized by activation and selectivity. Muscle activation was defined as the muscle's peak normalized EMG amplitude. Muscle selectivity was defined as the ratio of muscle activation for the muscle of interest over the sum of all seven muscles' peak activations.

Results indicated that Bicep I and II had the greatest potential for the clinical detection of SLAP lesions because both tests 1) elicited large LHBB activation, suggesting that during these tests more tension was applied to the biceps tendon, and also 2) remained highly selective for the LHBB, which should reduce the potential sources for confounding results. Also, tests that elicited promising LHBB behavior for either a single suite or for both activation and selectivity, shared design patterns relating to location of the applied load, forearm orientation, joint position, and line of pull. These characteristics should be further examined to determine their potential role in optimizing SLAP test design and improving clinical diagnostic techniques.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The shoulder complex is an inherently complicated system with regards to both

structure and function; hence improving prevention, detection, and treatment of

glenohumeral pathologies has been difficult.   Fortunately, shoulder biomechanics is an

expanding and developing field that has and will continue to play an instrumental role in

furthering the understanding of the anatomy and behavior of the shoulder complex and in

enhancing the ability of medicine to detect and repair various pathologies. Advancements

in the biomechanical analysis of the glenohumeral joint and in the ability of medicine to

manage shoulder injuries are closely related, and both biomechanics and medicine have

reaped considerable benefits from technological and scientific developments in medical

imaging and surgical techniques that have enabled a new perspective of the glenohumeral

joint with regards to both form and function.

http://www.shoulderdoc.co.uk/images/uploaded/SLAP%20region.jpg
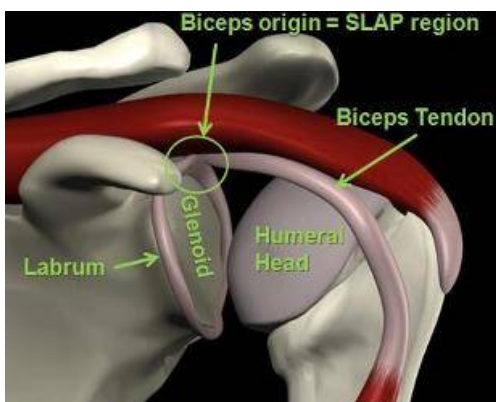
Figure 1: SLAP Lesion Injury Region

The advent of shoulder arthroscopy as a medical tool led to the initial

identification and description of glenoid labral tears in 1985, a glenohumeral

musculoskeletal pattern and abnormality that was previously undetectable [1]. The specific glenoid labral pathology, a superior labrum anterior-posterior tear was coined 'SLAP lesion' in 1990 (*Figure 1*) [32]. Although it has been more than two decades since SLAP lesions were defined and despite considerable advances in the understanding of glenohumeral biomechanics and glenoid labral pathologies, SLAP lesion detection remains difficult. Radiography and physical examination have proven useful for assessing a wide variety of orthopedic injury, but have shown limited potential with regards to SLAP lesion detection. Arthroscopy remains the 'gold standard' and the only definitive means of SLAP lesion diagnosis [18, 22, 33 4, 8]. An alternative to shoulder arthroscopy would be advantageous due to the invasiveness, financial cost, and patient risk associated with arthroscopy.

Recent developments in advanced imaging methods have drastically improved the diagnostic reliability of radiography, particularly in the detection of musculoskeletal patterns and injuries that previously, due to the low contrast of x-ray and computed tomography (CT), were impossible to identify with radiography. Although, magnetic resonance (MR) arthrography, specifically in high contrast, has shown some promise as a supplementary tool in SLAP lesion diagnosis, natural anatomic variants inherent in shoulder anatomy limit the reliability of radiographic diagnoses [3, 4, 7, 21, 26, 35]. Furthermore, problems with radiography follow those of arthroscopy; MR arthrography, for example, can be invasive, expensive, and dangerous, causing life threatening allergic reactions in some patients [5]. Therefore radiography is an imperfect means of SLAP lesion detection.

More than 20 provocative tests for the clinical evaluation of SLAP lesions are proposed in the literature. In most cases, the evaluation of these physical exams claim to have promising accuracy for the detection of SLAP lesions by their original authors [2, 19, 24, 27, 36, 37]. However, secondary studies fail to reproduce the initial findings, typically reporting much lower values for the sensitivity and specificity of the physical examination tests [8, 11, 14, 22, 28, 29]. The discrepancies between the findings of these studies most likely reflect two primary difficulties;

1) The clinical detection of SLAP lesions is hindered by the fact that SLAP lesions are rarely isolated; meaning they are frequently accompanied by other various glenohumeral pathologies which are potential sources for labral symptoms [3].

2) Differences in study protocols and problems associated with the methods used to verify accuracy of the design of these tests make comparisons between studies and verification of SLAP lesion tests difficult [8].

The bulk of the literature determines SLAP lesion test diagnostic accuracy utilizing a single verification method. Typically a patient with a suspected SLAP lesion performs the provocative tests of interest in a clinical setting before shoulder arthroscopy. The outcome of the SLAP lesion tests from the clinical evaluation is then verified with conclusive arthroscopic findings [7-9, 11, 14, 22, 23, 29]. The results of these comparative studies have significant quantitative discrepancies, but a fundamental qualitative conclusion recurs; no single SLAP lesion test has the sensitivity or specificity to independently determine the presence or absence of a SLAP lesion [7-9, 28]. Although previous studies attempt to assess the diagnostic accuracy of SLAP lesion tests, the analyses do little to

explain the reasons behind their apparent failure and rarely suggest or point to any means of improving the performance of the tests.

Although, clinically based evaluations of SLAP lesion tests account for the majority of studies to date, studies have also assessed test accuracy by attempting to validate the fundamental design behind various tests. Provocative SLAP lesion tests, by definition, function to provoke labral symptoms (primarily in the form of shoulder pain) as a positive diagnostic sign, by reenacting one of two injury mechanisms.

http://www.palmbeachshoulder.net/Joint-Problems.aspx
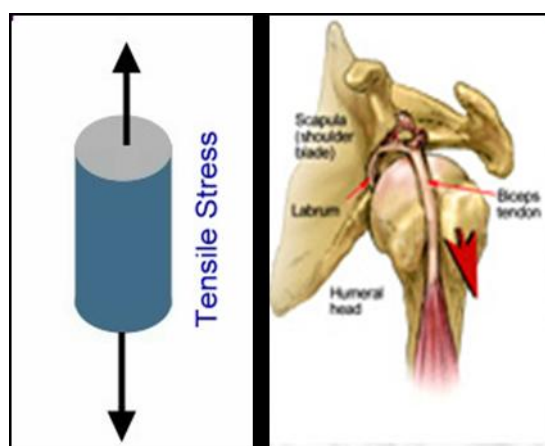
Figure 2: SLAP Lesion Injury Mechanism I

The first mechanism (*Figure 2*) elicits active tension in the biceps tendon and is typically associated with an acute traction trauma to the arm or elicited from repetitive overhead throwing injuries. The tensile load produced in the biceps tendon can pull and damage the superior labrum, the functional link between the insertion of the biceps tendon and the glenoid rim. The second injury mechanism produces passive compression of the humeral head and is often associated with a fall to outstretched arms (*Figure 3*).
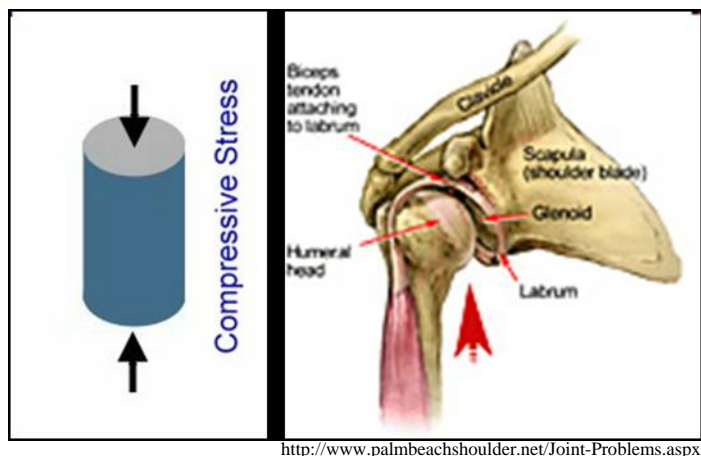
Figure 3: SLAP Lesion Injury Mechanism II

The compressive load causes superior humeral head translation within the glenohumeral joint and can result in a collision between the humerus and labrum, potentially damaging the soft tissue of the labrum[1] The ability of proposed tests to reenact the injury mechanisms that they were designed to replicate has been examined from a few different perspectives including anatomic[10, 17, 30] and electromyographic[10, 34] methods. The results of these studies illuminate the importance of design validation during the development of clinical testing procedures.

The results of these studies do not clearly define the most accurate test for SLAP lesion diagnosis. Therefore the purpose of this study was to use electromyography (EMG) to biomechanically assess the ability of seven provocative tests to create active tension in the biceps tendon by activating the long head of the biceps brachii (LHBB). The SLAP lesion tests in this study were expected to successfully elicit LHBB activity because they were designed by their original author to reproduce a SLAP lesion injury mechanism in that manner; hence this study was a means of verifying the design of SLAP lesion tests that are meant to reproduce the first SLAP lesion injury mechanism. Furthermore, this study also examined six other glenohumeral joint stabilizing muscles,

the short head of the biceps brachii (SHBB), anterior deltoid (DELT), pectoralis major (PECT), latissimus dorsi (LAT), infraspinatus (INFRA), and supraspinatus (SUPRA), with EMG to determine how effectively each test isolated the activation of the LHBB and to characterize the behavior of each of the glenohumeral joint stabilizing muscles. Selectively activating the LHBB should reduce confounding implications of labral symptoms elicited from a source other than a SLAP lesion. Also, slight modifications were made to each of the original authors' depiction of the tests to allow the use of the Biodex System II Dynamometer to improve the uniformity between each subject's anatomical orientation and performance for each test. Additionally, the Biodex System aided the attempt to control and limit differences that may have resulted from inconsistencies in the magnitude of load applied for each test and the impact of the variability in subject's strength and their respective ability to resist the applied load.

The primary objective of this study was to evaluate seven SLAP lesion tests, chosen based on the findings of a pilot study, in subjects with no history of shoulder pathology, using EMG according to two variables, muscle activation and muscle selectivity, to characterize particular aspects of LHBB behavior. Additionally, differences in the LHBB behavior between male and female gender groups were examined. Furthermore, a brief supplementary analysis characterized the behavior of the six other joint stabilizing muscles in the same manor as for the LHBB.

The hypotheses of this study was that there would be no difference between the seven SLAP lesion tests in the LHBB behavior for either variable, no crucial behavior differences were anticipated between tests for the other six glenohumeral joint stabilizing

muscles, and furthermore differences between gender groups were also not anticipated. The statistical hypotheses will be as follows:

$H_O : \mu_1 = \mu_2 = ... = \mu_7$ (All SLAP lesion tests elicit the same value in)

- LHBB activation

- LHBB selectivity

- Gender groups

$H_A : \mu_1 = \mu_2 = ... = \mu_7$ (All SLAP lesion tests elicit a different value in)

- LHBB activation

- LHBB selectivity

- Gender groups

Operational Definitions

This study involves two dependent variables that characterize a specific behavior of the individual muscles. The principal interest for SLAP lesion detection was the LHBB behavior, but regardless of the muscle analyzed, for each respective muscle the variables were quantified by the same method for each of the seven respective muscles.

- *LHBB activation*: the maximum LHBB activity elicited
  - as indicated by the peak LHBB amplitude of the normalized EMG signal recorded during each respective provocative tests, units of percent maximum contraction, range ideally between zero and 100%
- *LHBB Selectivity*: the ratio depicting the ability of a respective provocative test to selectively activate the LHBB

o as indicated by the ratio of the LHBB activation defined above, over the sum of all seven glenohumeral muscles respective activations, defined by the same method above but with respect to each muscle, the normalized maximum peak EMG signal amplitudes elicited during a respective provocative test, unitless due to the ratio of units of percent maximum contraction over units of percent maximum contraction, range between zero and one

Limitations

The results of this study are limited to individuals who are represented by the sample population: healthy males and females who have no history of shoulder pathology. The findings in this study are only representative of individuals falling within the subject parameters noted above. It should be noted that patients with a suspected SLAP lesion may have considerable differences in muscle behavior than those who have had no history of shoulder pathology, like the cohort in this study.

Delimitations

The results of this study are applicable to all physicians and clinicians using any of the seven tests because the focus is simply to verify the tests' design by assessing the ability of each test to reproduce a specific SLAP lesion injury mechanism. In elaboration, this study allows the verification of the test design, which is limited in other studies with subjects who have a shoulder injury as a successful test. The findings of such studies may not accurately represent the fundamental ability of the test to reproduce the injury mechanism.

LITERATURE REVIEW

This chapter summarizes the findings of relevant journal articles that have been published regarding SLAP lesions to date. Topics include shoulder and labral anatomy, the history of SLAP lesions, and the literature containing evaluations of the seven provocative SLAP lesion tests of interest for the present study described in this thesis

Shoulder Anatomy

The shoulder complex (*Figure 4*) is an intricate system containing four bones (clavicle, humerus, thorax, and scapula), three anatomical articulations (acromioclavicular, sternoclavicular, and glenohumeral), and one functional articulation (scapulothoracic), which is supported by ligamentous structures, soft tissues, and the musculature surrounding of the shoulder girdle.

http://www.pt.ntu.edu.tw/hmchai/Kinesiology/KINupper/Shoulder.files/ShoulderStructure.htm
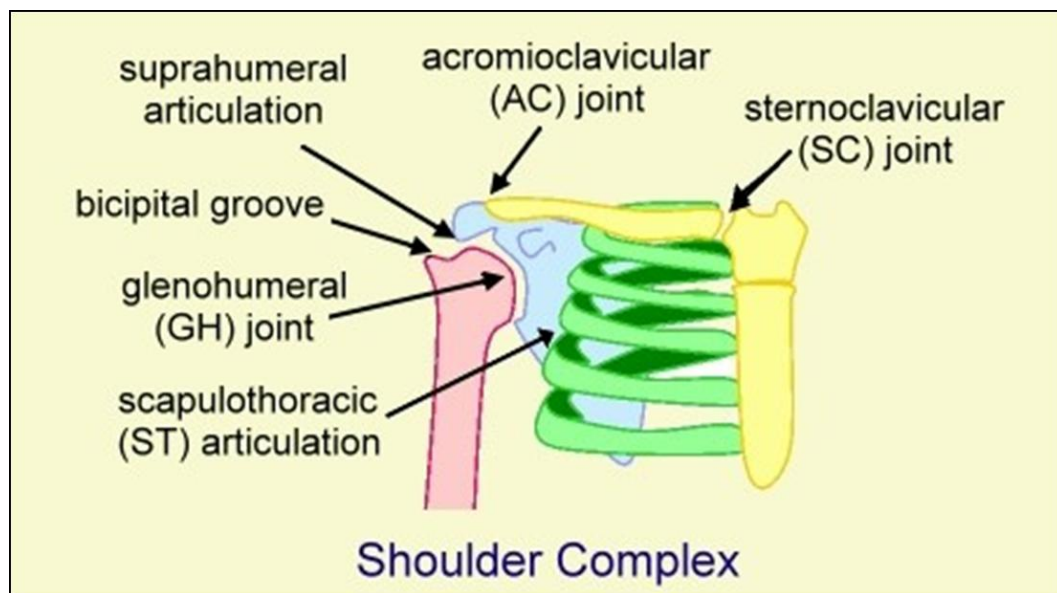
Figure 4: Shoulder Complex - Bony Anatomy

The interaction of these components produces the most dynamic and mobile joint complex in the body. The stability of this uniquely mobile joint, and specifically the glenohumeral ball and socket joint (*Figure 5*), is maintained by a number of static and dynamic stabilizing structures. The articular surfaces of the proximal humerus and glenoid are mismatched with regards to size and orientation, which grants the joint extreme mobility, and essentially eliminates bony stability[21].
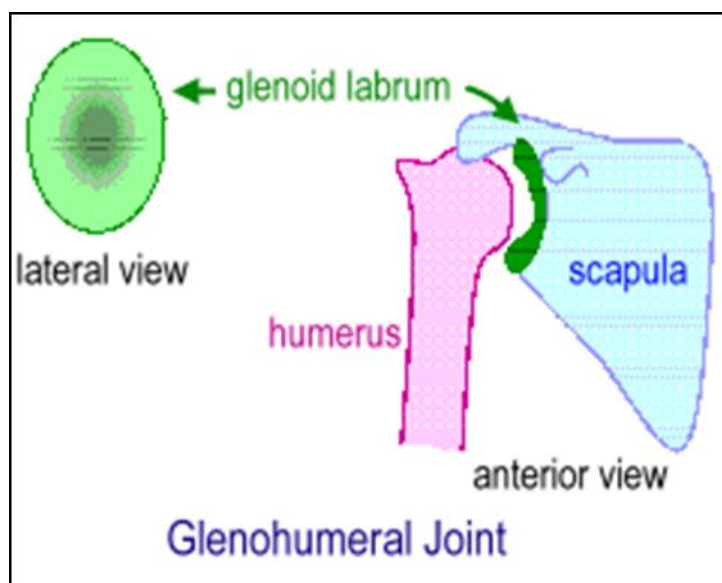
Figure 5: Glenohumeral Joint Anatomy

Shoulder stability is maintained by a complex web of contributors including the static soft tissue structures of the joint itself and the musculature surrounding the shoulder girdle. A recent publication by Veeger and colleagues on shoulder biomechanics articulately noted that shoulder function is the 'perfect compromise between stability and mobility'[1]. Clearly, the stability of the shoulder can be easily compromised due to the number of components and the complexity of their interactions. Glenoid labral pathologies can hinder the careful balance required by this unique biomechanical system. Glenoid labral musculature, surrounding connective tissues, and negative intra-articular

pressure are all proposed constituents involved in maintaining the stable position of the humeral head within the glenoid. The labrum itself plays a valuable role in joint stability. The glenoid labrum creates a suction effect on the humeral head and it increases the depth of the glenoid cavity by fifty percent. Hence, the presence of glenoid labral pathologies inherently affects stability of the glenohumeral joint.

SLAP Lesions

In the last century, the development of medical imaging techniques has radically expanded the understanding of human anatomy. Radiography began with the discovery of the x-ray in the late nineteenth century, and its diagnostic value was quickly realized. Today the term radiography encompasses the range of imaging modalities not limited to computed tomography (CT) and magnetic resonance imaging (MRI). Both CT and MRI create three dimensional reconstructed images, which improve on the flat, two dimensional nature of the x-ray. MRI has far greater contrast than CT, which enables various soft tissues such as muscles and ligaments to be distinguished, greatly aiding the understanding of musculoskeletal anatomy. Magnetic resonance (MR) arthrography, where a contrast medium is injected into a joint or region of interest prior to MRI to further improve tissue differentiation, has been particularly useful for examining fine musculoskeletal pathologies including lesions of the shoulder[4]. Clearly, radiography has allowed human anatomy and physiology to be viewed in a new perspective, and specifically, advanced imaging methods have helped to illuminate the difficult form, function, and carefully balanced means of maintaining the stability of the shoulder complex.

The introduction of shoulder arthroscopy enabled the characterization of musculoskeletal pathologies that were previously unidentifiable with open surgical techniques, medical imaging modalities, or through the use of any other medical tools. In this manner, the complex musculoskeletal structure of the shoulder greatly benefited from the advent of shoulder arthroscopy. Specifically, in 1985 glenoid labral lesions were first described in throwing athletes after Andrews et al diagnosed 73 patients with the pathology after arthroscopic surgery. Andrews et al made several hypotheses based on observations during this early study, and they remain relevant today; 1) during throwing the biceps tendon undergoes large forces, 2) the most frequent location of glenoid labral tears is near the biceps tendon insertion at the anterior-posterior area of the glenoid (occurring in 83% of the glenoid labral lesion patients in the study by Andrews et al), and 3) the biceps tendon is likely the cause of glenoid labral lesion[1].

In 1990, Snyder et al coined the term superior labrum anterior-posterior (SLAP) lesion to simply identify the labral lesion first described by Andrews et al[32]. Interestingly, although almost two decades has passed since this publication, the difficulty associated with SLAP lesions detection without arthroscopy, which was noted in the publication, has not changed considerably. Snyder et al examined more than 700 shoulders with arthroscopy and found 27 SLAP lesions. SLAP lesions were further categorized into four grades of severity ranging from Type I (where fraying and a general degenerative appearance of the superior aspect of the labrum is present) to Type IV (where 'bucket handle' tears are present and often are displaced into the joint with the lesion extending into the biceps tendon). Furthermore, importance of this study is indicated by the frequency with which it is referenced in the literature. Snyder et al was

the first to acknowledge the frequent occurrence of other shoulder pathologies with SLAP lesions, and the findings supported and improved upon concepts relating to SLAP lesion injury mechanisms. The injury mechanisms were related to either a tensile load on the biceps tendon or a compressive load received on the labrum itself. The injury occurred from either traction to the arm from a sudden traumatic increase in load, from a repetitive tensile load seen in overhead throwing athletes, or from a compressive load caused from a fall to outstretched arms.

An EMG study during baseball pitching noted that peak biceps brachii muscle activity occurred following ball release, during the deceleration phase of the arm while throwing[15]. These findings supported Andrews et al's biomechanical evaluation of throwing in the 1985 manuscript, examining the elbow and shoulder moments using three dimensional high speed cinematography and computer assisted analysis. Andrews determined that during the peak acceleration phase of throwing, the elbow extends from $80°$ to $30°$ in a 25-ms period, producing a peak moment of 600 inch-pounds prior to deceleration. The hypothesis is that the burst of biceps activity at the beginning of the deceleration phase indicates that the biceps play a role in decelerating the joint and that the large mechanical moment noted may be dampened and controlled by the LHBB, supporting the possibility that the deceleration phase of throwing may be a likely cause of SLAP lesions[1].

The present findings and consensus in the literature continues to support the proposed SLAP lesion injury mechanisms suggested over twenty years ago in the first two SLAP lesion publications[1, 32], but contrarily there have been some unique case reports whose findings seem to question these mechanisms. Specifically, the role of

tension in the biceps tendon in SLAP lesions has been called into question.   A case study by Keefe et al discussed the potential need to reevaluate the pathomechanics behind SLAP lesion mechanisms due a patient with a SLAP lesion (arthroscopic verification) that did not have a biceps tendon. The patient could not recall a traumatic traction event, a fall to outstretched arms, and clearly the injury could not have resulted due to tension in the biceps tendon during overhead throwing, though the subject was an active throwing athlete. Although a lack of the biceps tendon may not be common for the general population, this case study may imply that the role of the tendon in the deceleration phase of throwing may need to be reevaluated for the general population and for the tendon's part in SLAP lesions[16].

Provocative Tests

Active Compression Test

In 1988 O'brien et al first proposed the Active Compression test. It was originally intended to assess acromioclavicular (AC) joint pathologies, but after anatomic validation using cadaver studies and following testing on subjects with suspected SLAP lesions, the authors claimed that the Active Compression test was useful for the clinical detection of SLAP lesions and various AC joint pathologies. The test was originally designed based on the description of a patient with a degenerative AC joint, who described the primary movements that reproduced his symptoms of pain. The author conducted a study of 318 patients with shoulder pain and reported promising findings. The results of the clinical tests were confirmed by either arthroscopic verification or radiography, and the findings alleged that the Active Compression test had 100% sensitivity, 99% specificity, a positive predictive value of 94.6%, and a negative

predictive value of 100% [27]. These results have not been reproduced in secondary studies, and one large potential source of error for the study is that medical imaging was used to verify the presence of SLAP lesion, and radiography is known to exhibit poor accuracy for SLAP lesion detection[8]. The Active Compression Test is one of the most evaluated SLAP lesion tests in the literature. Most studies indicate it performs with some promise, but in general high accuracy is not reported.

In response to questions associated with the initial study's findings and reliability of the accuracy for the Active Compression test, McFarland et al conducted a study with 426 patients all of which underwent arthroscopic confirmation and found 47% sensitivity, 55% specificity, a positive predictive value of 10%, and a negative predictive value of 91% [22]. This study clearly does not support previous findings, and again the discrepancy could be linked to the error associated with radiographic diagnoses and their use in the study.

Similar studies report findings which parallel the results of McFarland et al, including the 2001 study by Kim et al and 2006 study of Parentis et al. Both of the studies further categorized SLAP lesions into various subtypes, to assess potential improvements in clinical test performance when severity and type of SLAP lesion where taken into account. Unfortunately in both studies the accuracy of the Active Compression test was below 65 % regardless of the type of SLAP lesion[19, 29].

Though much less in number, several other studies have attempted to evaluate the accuracy of the Active Compression SLAP lesion test utilizing different test design verification methods, and these analyses are of particularly interest to the study in this thesis. A study in 2004 assessed the anatomical basis for the test, using MRI. The

findings suggested there was an anatomical basis for the test. The study suggests that

the internal rotation of the arm, required for the palm-up position of the test, causes

consistent physical contact between the superior labrum and lesser tuberosity, which

likely would be a source of pain for subjects with a damaged labrum. Furthermore, this

contact between articular surfaces is eliminated with internal rotation of the forearm as

the palm-down position requires. These findings support the anatomic validation of the

Active Compression Test because the test is considered positive for a SLAP lesion only

when the patient has labral symptoms during the palm-up portion of the test that are not

present during the palm-down portion of the test[30].

In 2006 another study proposed that Type II SLAP lesions may be best detected

with the Active Compression tests and EMG was used to determine which clinical tests in

the study elicited the most promising muscle behavior. The study found that strong

LHBB activity peak was elicited during the Active Compression test, indicating that the

test may be a better diagnostic tool than other tests in that study[34].

In 2008 a study also attempted to anatomically validate the Active Compression

test using two methods.   First, the objective was to quantify the active tension in the

biceps tendon using EMG and twelve healthy subjects. Second, the objective was to

quantify the passive tension in the tendon in five cadaver shoulders, using a custom

designed load cell to determine strain on the biceps tendon. In contrast to Parentis et al,

this study found that the anatomic basis of the Active Compression test was not valid[10].

Although the Active Compression Test is examined frequently in the literature,

the findings of these studies are limited, and this is a pattern that is repeated for the

remaining six tests examined in this study. Majority of the studies assess this test, and all

SLAP lesion tests, by a single comparative method. The clinical findings of the test are compared with the concrete arthroscopic diagnoses, and such a comparative analysis is has considerable limitations.   These comparative studies provide no indication as to why the test performed successfully or otherwise and furthermore, the tests provide no information or means of improving upon test performance.   Studies that examine tests using other methods such as with EMG and cadaver specimens, improve upon the comparative analysis, in that they provide information that potentially explains reasons for their performance. In the case of the Active Compression test, biomechanical analyses were seen in two studies, using EMG and cadaver, but more studies in this manner would benefit SLAP lesion tests.

<u>Speed's Test</u>

In 1998, Speed's Test was introduced to assess a variety of shoulder pathologies, and this study is frequently used today in the clinical setting. Bennett et al assessed 46 shoulders in 45 patients with arthroscopic confirmation, and determined that Speed's had a promising sensitivity of 90%, but found the test performed poorly for other accuracy measures with 14% specificity, a 23% positive predictive value, and a 83% negative predictive value[2]. Another study countered these findings, eliciting low sensitivity results for Speed's tests at 32%, 75% specificity, a 50% positive predictive value, and a 58% negative predictive value. This study concluded that Speed's was moderately specific, but the test was unlikely to influence the pretest diagnosis held by the clinician. The authors reiterated the fallibility of clinical assessments, because depending on the setting and population, they argue that predictive values vary inherently[14].

In 2007, another study examined the accuracy of Speed's to detect partial tears in the biceps tendon in 847 consecutive patients who underwent arthroscopy, and 40 of those had confirmed SLAP lesions. In this study, Speed's tests had a sensitivity of 50%, specificity of 67%, a positive predictive value of 8%, and negative predictive value of 96%. The frequent occurrence of other shoulder pathologies was attributed to the reason behind the poor behavior of Speed's and the anticipated unreliability of any clinical exam to detect partial tears of the biceps tendon. Of the 847 patients, 40 had partial bicep tendon tears, 34 had partial rotator cuff tears, three had anterior instability, two had impingement without rotator cuff tear, and 1 had degenerative arthritis. The study concluded that no single physical examination test can accurately predict the presence of a partial tear in the biceps tendon. The study also suggested that tests designed to produce tension in biceps tendon are not helpful in detecting partial tears of the bicep tendon[9]. Again the lack of valuable information that can be derived from these types of comparative studies must be reiterated, and Speed's has not been studied biomechanically or anatomically to date.

Pronated Load Test

The performance of the Pronated Load test has not been evaluated beyond the mention of promising sensitivity by Wilk et al in 2005. The test was designed to simulate the injury mechanism and peel back behavior seen during stimulation. The Pronated Load test is meant to have the promising behavior of the Pain Provocation Test which causes passive external rotation of the forearm, coupled with a position that enables large activity from the LHBB during contraction[36]. No biomechanical studies are presently available on the Pronated Load test.

Bicep Load I Test

In 1999, a new SLAP lesion test was proposed; the Bicep Load I Test. This provocative test was designed to detect SLAP lesions in subjects who have recurrent anterior shoulder dislocation, typically found in SLAP lesion Type II subjects. The original and only study evaluating this test was a cohort study, and evaluated 75 patients who all underwent arthroscopic surgery. The Bicep Load I test indicated that 12 subjects had SLAP lesions, and 10 of these were arthroscopically confirmed as Type II SLAP lesions. The resulting test sensitivity was 90.9%, specificity was 96.9%, positive predictive value was 83.0% and negative predictive value was 98.0%[20]. Although, the original findings are promising, the test is designed for SLAP lesion detection only in shoulders with recurrent dislocation and may not be as reliable for those patients without the additional shoulder pathology. Furthermore, no biomechanical or anatomic studies have evaluated this test.

Bicep Load II Test

In 2001, another SLAP lesion test was proposed, Bicep Load II test, as a complement to Bicep I. The Bicep Load II test was designed with the intent to detect isolated SLAP lesions. 127 subjects were evaluated in the study, 38 were positive for a SLAP lesion according to the Bicep Load II test, and 35 were confirmed to have SLAP lesions following arthroscopy. Again, promising accuracy was reported with 89.7% sensitivity, 96.6% specificity, 92.1% positive predictive value, and 95.5% negative predictive value[19]. These findings may be limited to isolated SLAP lesions, which is inherently uncommon.

In 2008, first study evaluating the ability of a combination of more than one provocative tests to detect Type II SLAP lesions was published. Several tests, including the Bicep Load II test, were included in this study, and interestingly the Bicep Load II test was categorized as a high performing test with respect to specificity. This study found that the combined findings from two relatively sensitive and one relatively specific test improved SLAP lesion detection accuracy dramatically, such that sensitivity was a minimum of 70% when one of the three tests were positive and specificity was a minimum of 90% when all three SLAP lesion tests were positive. Furthermore, in this study, the author explicitly stated that no single SLAP lesion test would have the capability, with regards to simultaneous strength in sensitivity and specificity, to be individually able to detect a Type II SLAP lesion[28]. Bicep Load II is another SLAP lesion test that has not been evaluated by means other than comparative assessment.

Resisted Supination External Rotation Test

In 2005, the Resisted Supination External Rotation was developed to mimic the peel-back mechanism associated with SLAP lesions. The study examined 40 athletes, of which 29 had SLAP lesions verified by arthroscopy. The results from the Resisted Supination External Rotation test were compared to those of the Crank test and the Active Compression test. Meyers et al claimed the Resisted Supination External Rotation test has better performance than both of the others, with a sensitivity of 82.8%, a specificity of 81.8%, a positive predictive value of 92.3%, and a negative predictive value of 64.3%[24]. Further evaluation of this test is needed, as the only study evaluating the test is this original study, and no biomechanical studies have been published to date.

Supination Sign Test

The Supination Sign test another provocative test designed to elicit labral symptoms as a means of SLAP lesion detection that is anatomically based. The Supination Sign Test was shown to have specificity and low sensitivity across four studies including Nakagawa et al, Guanche et al, Holtby et al, and Parentis et al resulting in comparable finding for sensitivity (14%, 12%, 43%, and 13% respectively for each study) and similarly for specificity (98%, 96%, 79%, and 93%).   Although in general the Supination Sign test has a high specificity, high specificity is likely not a good method for stand alone evaluation of the presence of a SLAP lesion[11 14 25 29]. Once again, no biomechanical assessment has been done.

In summary, no study has biomechanically assessed the accuracy and performance of these tests. Although many studies have attempted to determine test accuracy by comparative analysis and some studies have examined a single test anatomically or with EMG, further biomechanical assessment is necessary to properly evaluate the ability of these tests to aid in the detection of SLAP lesions in the clinical setting. A biomechanical evaluation of these tests, will not only help to verify the design of these test and provide an alternative method to quantify test accuracy, but biomechanical assessment could also provide valuable information as to how these tests may be improved.

METHODS

This chapter addresses the methodology and procedures that were used to acquire the data necessary to fulfill the purpose of this study. Topics that will be addressed in this chapter include the experimental protocol for this study, the original descriptions of each provocative SLAP lesion test and the modifications used in this study, the methods used to filter and analyze the EMG data, including the definitions and mathematical equations for muscle activation and muscle selectivity, and the statistical methods used to determine the significance of the data.

Experimental Protocol

Subject and IRB approval

A cohort of 21 healthy volunteers comprised of 11 females (24.7 $\pm$ 6.7 years, 168.4 $\pm$ 5.3cm, 66.9 $\pm$ 9.1kg) and 10 males (29.4 $\pm$ 10.6 years, 178.1 $\pm$ 6.6 cm, 80.0 $\pm$ 6.4kg) with right arm dominance and no history of shoulder pathology were recruited for subjects in this study. Subjects recruited were either college students at Boise State University or medical health professionals from the local area. All procedures were approved by the Institutional Review Board at Boise State University, and all participants read and signed a statement of informed consent prior to the start of testing.

Electromyography Apparatus and Subject Preparation

EMG was used to record muscle activity for seven muscles surrounding the dominant arm's glenohumeral joint including the long head of the biceps brachii (LHBB), short head of biceps brachii (SHBB), anterior deltoid (DELT), pectoralis major (PECT),

latissimus dorsi (LAT), infraspinatus (INFRA), and suprasinatus (SUPRA). Each

subject was instrumented with a single 44-gauge fine-wire indwelling electrode and six

surface bipolar silver-silver chloride EMG electrodes (Noraxon, USA Inc, Scottsdale,

AZ). The surface electrodes were positioned over the muscle belly and parallel with the

orientation of the muscle fibers, as seen below where a) LHBB and SHBB, b) DELT, c)

PECT, d) LAT, e) INFRA, and f) SUPRA (*Figure 6*)[6].
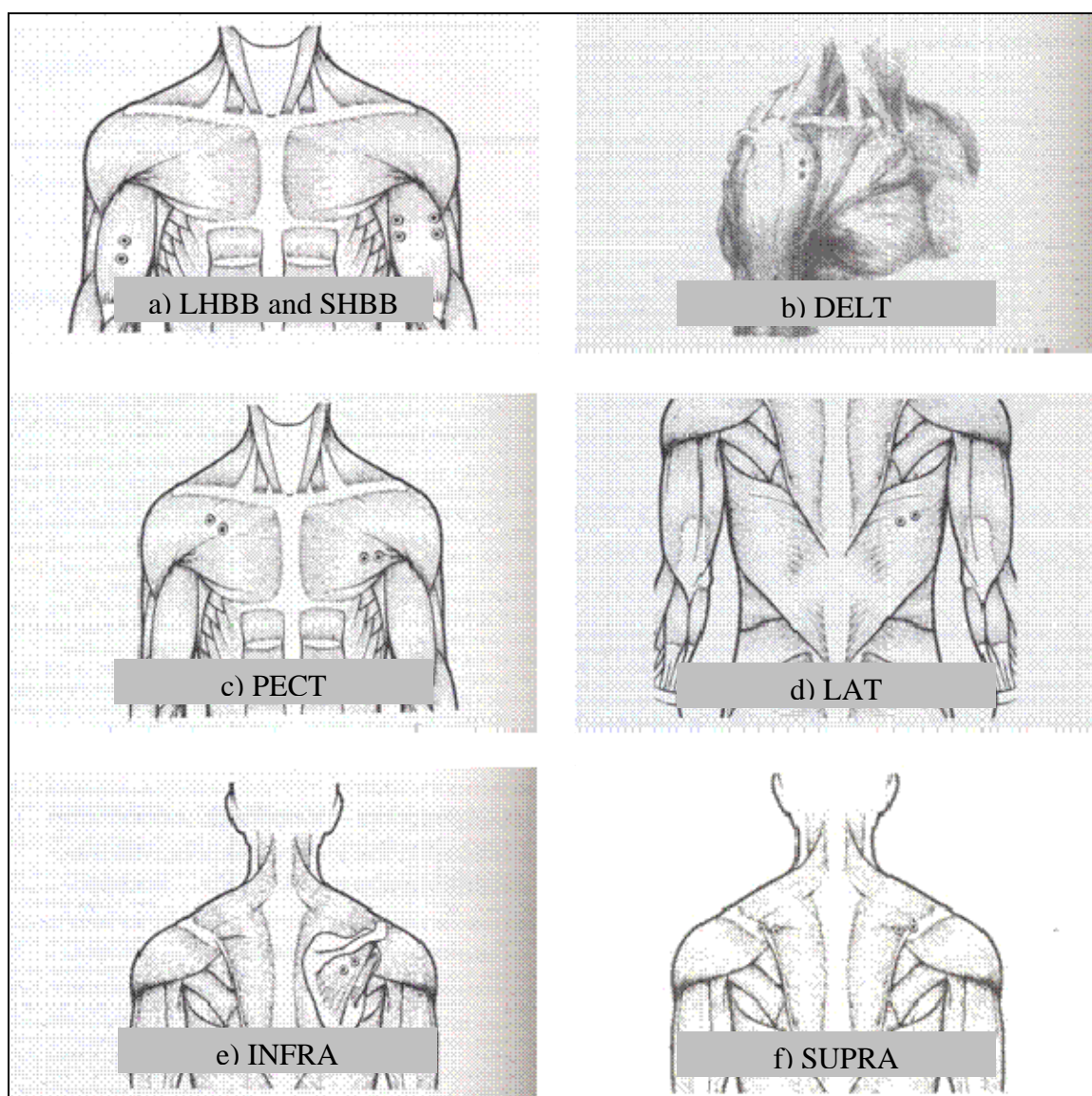
Figure 6: Electrode Placement for EMG (a – f)

An additional surface electrode was placed on the acromion process of the non-dominant shoulder to serve as a reference. Due to the location of the SUPRA deep to the trapezius, the indwelling electrode was necessary to acquire SUPRA activity. Using sterile techniques a certified medical technician placed the fine-wire indwelling electrode using a 27-guage sterile needle. EMG data were recorded using the Vicon Nexus Software (Vicon, Los Angelos, CA) at 1250 Hz using a Noraxon Telemyo 900 EMG system (Noraxon USA, Inc, Scottsdale, AZ).

Subject Protocol

Using established EMG protocols, each subject was asked to perform Maximum Voluntary Isometric contractions (MVICs) for each of the seven muscles in random order on a Biodex System II Dynamometer (Biodex Medical Systems, Shirly, NY). Modifications were made to the MVIC recommendations of Cram, Hintermeister, and Rowlands[6, 12, 31] to accommodate for the use of the Biodex System (*Table 1*).

Muscle	Joint Position	Resisted Maneuver
DELT	Arm at side	Shoulder flexion
LHBB / SHBB	Elbow flexed 90º, shoulder flexed 90º	Elbow flexion
INFRA	Arm abducted 45º, elbow flexed 90º	External Rotation
LAT	Shoulder flexed 90º, arm internally rotated	Shoulder extension
PECT	Arm abducted 90º, forearm supinated	Horizontal adduction
SUPRA	Arm abducted 90º, forward flexed 30º, and internally rotated	Maintain against resistance

Table 1. MVIC Joint Positions and Resisted Maneuvers

For each trial six seconds of data were recorded to ensure that the entire burst of muscle activity was captured during each MVIC. The subjects performed three trials for each MVIC and were asked to maximally contract for a count of three seconds. Subjects rested for thirty seconds between MVIC trials to avoid fatigue effects. For each MVIC, the peak amplitude of the EMG signal among the three trials was used to normalize the provocative test data to a percentage of effort.

Similarly seven provocative tests were performed in random order based on the descriptions of the original authors but with modifications to accommodate for use of the Biodex System. These tests were chosen based on the findings of a preliminary pilot study that evaluated clinical tests from relevant literature that were designed to reenact SLAP lesion injury mechanisms. Again, each subject performed three trials for a three second count for each test, six seconds of data were recorded for each trial, and the subjects rested for thirty seconds between trials to avoid fatigue affects.

Once all MVIC and SLAP lesion test trials had been completed the surface electrodes were removed from the subject, and a trained medical technician, using sterile techniques, removed the indwelling electrode from the SUPRA by applying gentle and steady traction to the leads. A sterile bandage and pressure were applied to the location where the indwelling electrode was removed. Each subject was advised to seek medical attention if an infection appeared to develop at the site, although infection was not anticipated.

Test Descriptions and Modifications

Each of the seven SLAP lesion tests performed in this study were provocative tests that were designed by their respective original authors to reproduce one SLAP

lesion injury mechanism, by activating the LHBB to induce tension in the biceps tendon. For the purposes of this study, modifications were possible and made for six of the seven SLAP lesion tests utilizing the Biodex System II Dynamometer to improve standardization between subjects and hopefully to reduce the potential for differences in muscle behavior or test performance due to variable subject and clinician strengths that could alter the intended test position or function. Tests requiring static resistance against an applied load maintained the static subject position through the stationary preset up of the Biodex System in isometric mode. Tests requiring dynamic resistance to an applied load were controlled by the Biodex System allowing a motion with a constant velocity regardless of the force applied by the subject through the isokinetic mode of the Biodex System. The original description of each test and the modifications employed in this study are noted below.

Active Compression Test (ACPU and ACPD)

The Active Compression Test has two positions, palm-down (ACPD) and palm-up (ACPU), which vary only by internal or external rotation of the arm. The patient is standing with the elbow in full extension, the shoulder is flexed to $90°$, and adducted $10-15°$ medial to the sagittal plane. For ACPD (*Figure 7*) the arm is maximally internally rotated such that the thumb points down. The patient is asked to resist a uniform downward load applied to their arm by the clinician. For ACPU (*Figure 8*) the initial patient positioning is unchanged except the arm is externally rotated such that the palm faces up. Again, the patient is asked to resist a uniform downward load applied by the clinician[27].

Figure 7: ACPU

Figure 8: ACPD

For the purpose of analysis and due to the nature of the subject population, a control group having no history of shoulder pathology, this study treated ACPU and ACPD as two independent tests. Both tests were modified such that the subject was seated in the Biodex System. The orientation of the subject's arm remained true to original description of the two test positions by O'Brien et al, but the subject was

asked to resist the stationary set-up of the arm of the Biodex System by attempting to lift his/her arm superiorly for both ACPD and ACPU.

Speed's Test

According to the original description of Speed's test (Speed), the patient is standing and resists a downward force applied to the upper extremity with the elbow extended, forearm supinated, and arm elevated to $90°$ [2]. In this study the orientation of the subject's arm remained similar to the original definition, but the test was modified into a dynamic movement controlled by the Biodex System. The subject's arm started hanging beside and parallel to the body with the palm facing up (*figure 9*), and then the subject was asked to raise the arm (flex the shoulder) with as much force as possible to $90°$. Regardless of the force exerted by the subject, motion was restricted to a constant velocity by the Biodex System in the isokinetic setting of $60°$ per second.

Figure 9: Speeds Starting Position

Pronated Load Test

In the original description, the patient is in the seated position with elbow flexed to $90°$, the arm abducted to $90°$, maximally externally rotated, and the forearm is fully pronated. The patient is then asked to perform an isometric contraction of the biceps (a 'curl' with the forearm pronated)[36]. The Pronated Load test (ProLoad) was negligibly modified for this study. The subject sat in the original orientation in the Biodex System, the subject's arm was supported just proximal to the elbow. The subject was asked to perform an isometric bicep contraction (pronated curl) which was resisted by the static set up of the Biodex System.

Bicep Load I Test

Figure 10: Bicep Load I

According to the original author's definition of the Bicep Load I test (Bicep I), the patient is in the supine position when an anterior apprehension test is performed starting with the arm abducted $90°$ with the forearm fully supinated[20]. Bicep I was modified such that the patient was seated in the Biodex System, in the same position

as ProLoad, except the forearm was fully supinated (*Figure 10*). The subject was asked to perform a bicep contraction (a traditional 'curl'), which was resisted by the static set up by the Biodex System.

Bicep Load II Test

The patient is supine with the arm abducted to $120°$ degrees, the elbow flexed to $90°$ degrees, and the forearm fully supinated.

Figure 11: Bicep Load II

The patient is then asked to flex the elbow against the resistance of the clinician[19]. For this study the modification for Bicep Load II test (Bicep II) paralleled those made to Bicep I except the arm was abducted to $120°$ degrees instead of $90°$ (*Figure 11*).

Resisted Supination External Rotation Test

The original authors describe putting the patient in the supine position with scapula near the edge of an evaluation table; the patient's arm is supported by the physician at the wrist, with the arm abducted to $90°$ and the elbow flexed between $65°$ and $70°$ degrees. The clinician then externally rotates the arm while the patient is

asked to supinate the forearm[24]. The Resisted Supination External Rotation test

test was essentially unchanged for this study (*Figure 12*), and the movement was not

controlled by the Biodex System because the position and motion could not be

recreated with the Biodex System for all subjects. One certified athletic trainer

performed RSER with each subject in the study in the supine position on the Biodex

System.
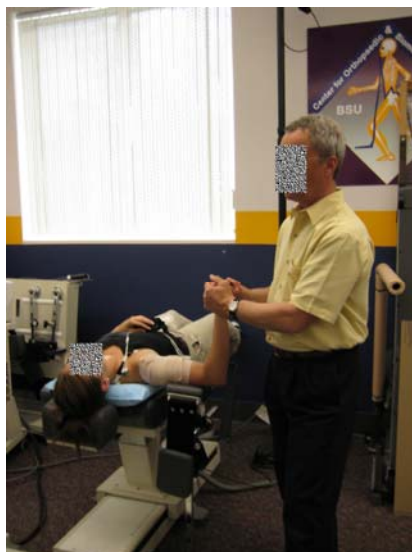
Figure 12: RSER Starting Position

Supination Sign Test

As originally defined, the Supination Sign test (Yergason), in the seated position

with the elbow flexed to $90°$ and forearm fully pronated, the patient is asked to

attempt to supinate the forearm while the physician resists the attempted motion while

holding the wrist[37]. Yergason was scarcely modified in this study; as the patient

maintained the defined orientation but the forearm was fastened to the static arm of

the Biodex System (*Figure 13*). The subject was asked to attempt to supinate the

forearm against the static setup of the Biodex System.

Figure 13: Yergason's

Electromyography Analysis

The raw EMG signals were filtered, normalized, and then analyzed to characterize muscle behavior using custom MATLAB software.   The raw EMG signals were processed a traditional EMG filtering technique that is frequently employed with EMG and noted in the literature. After processing the EMG signals, numerical values were calculated for the LHBB activation and LHBB selectivity as a means of characterizing LHBB behavior.   Supplementary calculations were made for the muscle activations and muscle selectivities of the remaining six glenohumeral muscles in this study.

Initial EMG Processing

During all testing, EMG data from each muscle were acquired at 1250 Hz, and the raw data was band-pass filtered from 16 to 500 Hz by the data collection unit internally prior to transmission of the data to the wireless receiver for further processing. Next, custom MATLAB software was used to further process, normalize, and analyze the EMG signals.

EMG Filtering Technique

The majority of EMG signals that were collected, the LHBB, SHBB, DELT, PECT, and SUPRA, were filtered by a traditional smoothing technique and band-pass filtered from 20 to 500 Hz, and then the signals were rectified and smoothed using a root mean square algorithm in combination with a 20-ms forward moving window average.

Normalizing Provocative Test Data with MVIC Maximums

The provocative test EMG signals were normalized to a percentage of effort based on the peak EMG amplitude elicited during each muscle's respective Maximum Voluntary Isometric Contraction (MVIC). Ideally the normalized and filtered EMG signals for each provocative test would have a muscle activation range of zero to 100% MVIC. Muscle activation and muscle selectivity were calculated for each muscle during each test.

Muscle Activation

Muscle activation was used to determine how effective each SLAP lesion test was at causing the individual muscles to activate and was defined as the peak muscle activities elicited during the three normalized trials.

Muscle Selectivity

The ability of each provocative test to isolate the LHBB is important for diagnosing SLAP lesions due to the common association of SLAP lesions with other shoulder pathologies. Therefore in this study, a ratio depicting the ability of each test to selectively activate each muscle was calculated. The muscle selectivity for each test was defined as the ratio of the peak activation of the muscle of interest over the sum of peak activations for all seven muscles examined in the study. For example, a selectivity ratio

of 1.0 for any muscle, N, would indicate that muscle N was the only active muscle contributing to the EMG signal while the other six muscles remained inactive. For each test the selectivity for muscle N was calculated using the following equation.

$$N\_SelectivityRatio = \frac{A_N}{\sum(A_{LHBB} + A_{SHBB} + A_{DELT} + A_{PECT} + A_{LAT} + A_{INFRA} + A_{SUPRA})}$$

- where N is the muscle of interest (LHBB, SHBB, DELT, PECT, LAT, INFRA, or SUPRA)

- where $N\_SelectivityRatio$ is the selectivity ratio of muscle N

- where A_N is the peak muscle activation for muscle N

Statistical Analysis

Statistical analysis was conducted using SPSS Statistics Software 17.0 for Windows to determine significance of the data, specifically, differences in maximum muscle activations and muscle selectivities for each test, between tests, and between male and female groups. A repeated measures analysis of variance (ANOVA) test was performed to identify significant differences between provocative tests for each individual muscle. A pair-wise T-test post-hoc analysis was performed to compare results between each test using a p-value sliding scale Bonferroni adjustment[13]. Likewise, a paired-sample T-test was used to examine potential differences in muscle activation (p = 0.05) between male and female groups.

REFERENCES

1.   Andrews, J., W. Carson, Jr, and W. McLeod, *Glenoid labrum tears related to the long head of the biceps.* Am J Sports Med, 1985. **13**(5): p. 337-341.

2.   Bennett, W.F., *Specificity of the Speed's Test: Arthoscopic Technique for Evaluating the Biceps Tendon at the Level of the Bicipital Groove.* The Journal of Arthroscopic and Related Surgery, 1998. **14**(8): p. 789-796.

3.   Chandnani, V., et al., *Glenoid labral tears: prospective evaluation with MRI imaging, MR arthrography, and CT arthrography.* Am. J. Roentgenol., 1993. **161**(6): p. 1229-1235.

4.   Chang, D., et al., *SLAP lesions: Anatomy, clinical presentation, MR imaging diagnosis and characterization.* European Journal of Radiology, 2008. **68**(1): p. 72-87.

5.   Chundru, U., *Magnetic Resonance Arthrography.* Musculoskeletal, 2009.

6.   Cram, J.R. and G.S. Kasman, *Introduction to surface electromyography.* 1998, Gaithersburg, MD: Aspen Publishers Inc.

7.   DaSilva, J.J., A.G. McNickle, and B.J. Cole, *Arthroscopic Superior Labrum Anterior to Posterior Repair.* Operative Techniques in Orthopaedics, 2008. **18**(1): p. 53-61.

8.   Dessaur, W. and M. Magarey, *Diagnostic accuracy of clinical tests for superior labral anterior posterior lesions: a systematic review.* Journal of Orthopaedic and Sports Physical Therapy, 2008. **38**(6): p. 341-352.

9.   Gill, H.S., et al., *Physical Examination for Partial Tears of the Biceps Tendon.* Am J Sports Med, 2007. **35**(8): p. 1334-1340.

10.   Green, R.A., et al., *An evaluation of the anatomic basis of the O'Brien active compression test for superior labral anterior and posterior (SLAP) lesions.* Journal of Shoulder and Elbow Surgery, 2008. **17**(1): p. 165-171.

11.   Guanche, C.A. and D.C. Jones, *Clinical Testing for Tears of the Glenoid Labrum.* The Journal of Arthroscopic and Related Surgery, 2003. **19**(5): p. 517-523.

12.   Hintermeister, R.A., et al., *Electromyographic Activity and Applied Load During Shoulder Rehabilitation Exercises Using Elastic Resistance.* The American Journal of Sports Medicine, 1998. **26**(2): p. 210-220.

13.   Holm, S., *A simple sequentially rejective multiple test procedure.* Scandinavian Journal of Statistics, 1979. **6**: p. 65-70.

14.   Holtby, R. and H. Razmjou, *Accuracy of the Speed's and Yergason's Tests in Detecting Biceps Pathology and SLAP Lesions: Comparison With Arthroscopic Findings.* The Journal of Arthroscopic and Related Surgery, 2004. **20**(3): p. 231-236.

15.   Jobe, F. and D. Moynes, *Delineation of diagnostic criteria and a rehabilitation program for rotator cuff injuries.* Am J Sports Med, 1982. **10**: p. 336-339.

16.   Keefe, D.T., Lowe, WR, *Symptomatic Superior Labral Anterior Posterior Lesion With Absence of the Long Head of the Biceps Tendon.* The American Journal of Sports Medicine, 2005. **33**(11): p. 1746-1750.

17.   Keren J. Shanley, R.A.G., Nicholas F. Taylor,, *An evaluation of the anatomical basis of the Biceps Load tests I and II for superior labral anterior and posterior (SLAP) lesions.* Clinical Anatomy, 2008. **21**(7): p. 647-651.

18.   Kibler, W.B., *Specificity and Sensitivity of the Anterior Slide Test in Throwing Athletes With Superior Glenoid Labral Tears.* The Journal of Arthroscopic and Related Surgery, 1995. **11**(3): p. 296-300.

19.   Kim, S.-H., et al., *Biceps Load Test II: A Clinical Test for SLAP Lesions of the Shoulder.* The Journal of Arthroscopic and Related Surgery, 2001. **17**(2): p. 160-164.

20.   Kim, S.-H., K.-I. Ha, and K.-Y. Han, *Biceps Load Test: A Clinical Test for Superior Labrum Anterior and Posterior Lesions in Shoulders With Recurrent Anterior Dislocations.* The American Journal of Sports Medicine, 1999. **27**(3): p. 300-303.

21.   Lugo, R., P. Kung, and C.B. Ma, *Shoulder biomechanics.* Shoulder Imaging European Journal of Radiology, 2008. **68**(1): p. 16-24.

22.   McFarland, E.G., T.K. Kim, and R.M. Savino, *Clinical Assessment of Three Common Tests for Superior Labral Anterior-Posterior Lesions.* The American Journal of Sports Medicine, 2002. **30**(6): p. 810-815.

23.   Munro, W. and R. Healy, *The validity and accuracy of clinical tests used to detect labral pathology of the shoulder â€" A systematic review.* Manual Therapy. **In Press, Corrected Proof**.

24.   Myers, T.H., J.R. Zemanovic, and J.R. Andrews, *The Resisted Supination External Rotation Test: A New Test for the Diagnosis of Superior Labral Anterior Posterior Lesions.* The American Journal of Sports Medicine, 2005. **33**(9): p. 1315-1320.

25.   Nakagawa S, Y.M., Hayashida K, Obata M, Fuckushima S, Miyazaki Y., *Forced shoulder abduction and eblow flexion test: a new simple clinical test to detect superior labral injury in the throwing shoulder.* Arthroscopy, 2005. **21**: p. 1290-1295.

26.   Nam, E.K. and S.J. Snyder, *The diagnosis and treatment of superior labrum, anterior and posterior (SLAP) lesions.* The American Journal of Sports Medicine, 2003. **31**(5): p. 798-810.

27.   O'Brien, S.J., et al., *The Active Compression Test: A New and Effective Test for Diagnosing Labral Tears and Acromioclavicular Joint Abnormality.* The American Journal of Sports Medicine, 1998. **26**(5): p. 610-613.

28.   Oh, J.H., et al., *The Evaluation of Various Physical Examinations for the Diagnosis of Type II Superior Labrum Anterior and Posterior Lesion.* Am J Sports Med, 2008. **36**(2): p. 353-359.

29.   Parentis, M.A., et al., *An Evaluation of the Provocative Tests for Superior Labral Anterior Posterior Tears.* Archives of Physical Medicine and Rehabilitation, 2005. **34**(2): p. 1-4.

30. Parentis, M.A., et al., *An Anatomic Evaluation of the Active Compression Test.* Journal of Shoulder and Elbow Surgery, 2004. **13**(4): p. 410-416.

31. Rowlands, L., et al., *Kinesiology of the Empty Can Test.* Am J Phys Med Rehabil, 1995. **74**(4): p. 302-304.

32. Snyder, S.J., et al., *SLAP lesions of the shoulder.* Arthroscopy: The Journal of Arthroscopic & Related Surgery, 1990. **6**(4): p. 274-279.

33. Stetson, W.B. and K. Templin, *The Crank Test, the O'Brien Test, and Routine Magnetic Resonance Imaging Scans in the Diagnosis of Labral Tears.* The American Journal of Sports Medicine, 2002. **30**(6): p. 806-809.

34. Swaringen, J.C., et al., *Electromyographic analysis of physical examination tests for type II superior labrum anterior-posterior lesions.* Journal of Shoulder and Elbow Surgery, 2006. **15**(5): p. 576-579.

35. Veeger, H.E.J. and F.C.T. van der Helm, *Shoulder function: The perfect compromise between mobility and stability.* Journal of Biomechanics, 2007. **40**(10): p. 2119-2129.

36. Wilk, K.E., et al., *Current Concepts in the Recognition and Treatment of Superior Labral (SLAP) Lesions.* Journal of Orthopaedic and Sports Physical Therapy, 2005. **35**: p. 273-291.

37. Yergason, R.M., *Supination Sign.* 1995.

APPENDIX

Manuscript for Submission to the Journal of Shoulder and Elbow Surgery

1   Abstracts for this study have been submitted and accepted for presentation at two

2   annual conferences. First, the study will be presented as a podium at the 2009 Northwest

3   Biomechanics Symposium (NWBS) at Washington State University, June 5th and 6th in

4   Pullman, WA.   Also, the study will be presented at the 2009 Annual Meeting of the

5   American Society of Biomechanics (ASB) at Pennsylvania State University, August 26th

6   through 29th in State College, PA. This manuscript has not been submitted for journal

7   publication; furthermore no portion of the data, methods, results, or findings from this

8   work have been previously submitted, published, or printed with the exception of the

9   abstracts for the conference submissions noted above.

10   This manuscript has been read and approved by all authors, and each author

11   believes the manuscript to be honest work.   Dr. Michelle B. Sabick should be noted as

12   the corresponding author for future inquiry with regards to this manuscript; her contact

13   information is as follows:

14

15   **Corresponding Author:** Dr. Michelle B. Sabick, PhD

16   **Address:** Boise State University, Department of Mechanical and Biomedical Engineering,

17   ET 204, 1910 University Dr., Boise, ID 83725-2075

18   **Office Phone Number:** 208.426.5653

19   **Fax Number:** 208.426.4800

20   **E-mail Address:** msabick@boisestate.edu

21

22   Vanessa J.C. Wood, MS, _____

23   This author, their immediate family, and any research foundation with which they

24   are affiliated did not receive any financial payments or other benefits from any

25   commercial entity related to the subject of this article.

26

27   Michelle B. Sabick, PhD, _____

28   This author, their immediate family, and any research foundation with which they

29   are affiliated did not receive any financial payments or other benefits from any

30   commercial entity related to the subject of this article.

31

32   Ron P. Pfeiffer, EdD, _____

33   This author, their immediate family, and any research foundation with which they

34   are affiliated did not receive any financial payments or other benefits from any

35   commercial entity related to the subject of this article.

36

37   Seth M. Kuhlman, MS, _____

38   This author, their immediate family, and any research foundation with which they

39   are affiliated did not receive any financial payments or other benefits from any

40   commercial entity related to the subject of this article.

41

42   Jason H. Christensen, _____

43   This author, their immediate family, and any research foundation with which they

44   are affiliated did not receive any financial payments or other benefits from any

45   commercial entity related to the subject of this article.

46

47   Mike J. Curtin, MD, _____

48   This author, their immediate family, and any research foundation with which they

49   are affiliated did not receive any financial payments or other benefits from any

50   commercial entity related to the subject of this article.

51

61

62 *Title Page*

63 **GLENOHUMERAL MUSCLE ACTIVATION**

64 **DURING PROVOCATIVE TESTS DESIGNED TO DIAGNOSE SUPERIOR**

65 **LABRUM ANTERIOR-POSTERIOR LESIONS**

66 [1,2] Vanessa J.C. Wood, MS, [1,2] Michelle B. Sabick, PhD, [1,3] Ron P. Pfeiffer, EdD, ATC,

67 LAT [1,2], Seth M. Kuhlman, MS, [1,2] Jason H. Christensen, [4] Mike J. Curtin, MD

68 [1] Center for Orthopaedic & Biomechanics Research, Boise State University

69 [2] Department of Mechanical and Biomedical Engineering, Boise Statue University

70 [3] Department Kinesiology, Boise State University

71 [4] Intermountain Orthopaedics, Boise, Idaho

72

73 **Corresponding Author:** Dr. Michelle B. Sabick, PhD

74 **Address:** Boise State University, Department of Mechanical and Biomedical Engineering,

75 ET 204, 1910 University Dr., Boise, ID 83725-2075

76 **Office Phone Number:** 208.426.5653

77 **Fax Number:** 208.426.4800

78 **E-mail Address:** msabick@boisestate.edu

79

84 **Abstract**

85 **BACKGROUND**
86 Despite considerable medical advances, arthroscopy remains the only definitive means of
87 Superior Labrum Anterior-Posterior (SLAP) lesion diagnosis. Natural shoulder anatomic
88 variants limit the reliability of radiographic findings and clinical evaluations are not
89 consistent. Accurate clinical diagnostic techniques would be advantageous due to the
90 invasiveness, patient risk, and financial cost associated with arthroscopy. The purpose of
91 this study was to examine the behavior of the joint stabilizing muscles in promising
92 provocative tests for SLAP lesions. Electromyography was used to characterize the
93 muscle behavior, with particular interest in the long head biceps brachii, as activation of
94 the long head and subsequent tension in the biceps tendon should elicit labral symptoms
95 in SLAP lesion patients.
96
97 **METHODS**
98 Volunteers (N=21) without a history of shoulder pathology was recruited for this study.
99 The tests analyzed were Active Compression, Speed's, Pronated Load, Biceps I, Biceps II,
100 Resisted Supination External Rotation, and Supination Sign. Tests were performed on a
101 dynamometer to improve reproducibility. Muscle activity was recorded for the long and
102 short heads of the biceps brachii, anterior deltoid, pectoralis major, latissimus dorsi,
103 infraspinatus, and supraspinatus. Muscle behavior for each test was characterized by peak
104 activation and selectivity.
105
106 **RESULTS**
107 Speed's, Active Compression Palm-Up, Bicep I and Bicep II, produced higher long head
108 activations. Resisted Supination External Rotation, Bicep I, Bicep II, and Yergason's,
109 produced higher long head selectivities.
110
111 **CONCLUSION**
112 Bicep I, and Bicep II elicited promising long head behavior (high activation and
113 selectivity). Speed's and ACPU elicited large long head activity, and Resisted Supination
114 and Yergason's elicited selective long head activity. These top performing tests utilize a
115 unique range of test variables that may prove valuable for optimal SLAP test design and
116 performance.
117
118 **LEVEL OF EVIDENCE:** Diagnostic Study Level I
119
120 **KEY WORDS:** SLAP, Superior Labrum Anterior Posterior Lesion, provocative test,
121 long head biceps brachii, diagnoses
122

123 *Introduction.*

124   The advent of shoulder arthroscopy as a medical tool led to the description of

125 glenoid labral tears in 1985 [1], and superior labrum anterior-posterior tears were coined

126 'SLAP lesions' in 1990 [30]. Although it has been almost two decades since SLAP lesions

127 were defined, diagnosis remains difficult [17, 21, 31] despite considerable advances in the

128 understanding of glenohumeral biomechanics and glenoid labral pathologies. In spite of

129 these advances, arthroscopy remains the only definitive means of SLAP lesion detection [4,

130 8]. Accurate clinical diagnostic techniques, as an alternative to shoulder arthroscopy,

131 would be advantageous due to the invasiveness, financial cost, and patient risk associated

132 with arthroscopy.

133   Radiography and physical examination have proven useful for assessing a wide

134 variety of orthopedic injury, but have shown limited potential with regards to SLAP

135 lesion detection. Though radiography, particularly MR arthrography in high contrast, has

136 shown some promise as a supplementary tool in SLAP lesion diagnosis, natural anatomic

137 variants limit the reliability of all radiographic diagnoses. Furthermore, parallel to

138 arthroscopy, radiography can be invasive, expensive, and dangerous, causing life

139 threatening allergic reactions [5] in some patients, rendering radiography an imperfect

140 means of SLAP lesion detection [3, 4, 7].

141   More than 20 provocative tests for the clinical evaluation of SLAP lesions are

142 proposed in the literature. In most cases, the evaluation of the physical exams by the

143 original authors reveals promising accuracy for the detection of SLAP lesions [2, 18, 19, 23, 24,

144 33, 34]. However, secondary studies often fail to reproduce the initial findings, typically

145   reporting much lower values for the sensitivity and specificity of the physical

146   examination tests [8, 12, 15, 21, 25, 26]. The discrepancies between the findings most likely

147   reflect two primary difficulties: 1) the clinical detection of SLAP lesions is hindered by

148   the fact that SLAP lesions are rarely isolated; meaning they are frequently accompanied

149   by other various glenohumeral pathologies which are potential sources for labral

150   symptoms [3], and 2) differences in study protocols and problems associated with the

151   methods used to verify accuracy of the physical examinations make comparisons between

152   studies difficult [8].

153   The bulk of the literature assesses SLAP lesion tests by determining diagnostic

154   accuracy through a single verification method. Typically a patient with a suspected

155   SLAP lesion performs the provocative tests of interest in a clinical setting before

156   shoulder arthroscopy. The outcome of the SLAP lesion test is then verified with

157   conclusive arthroscopic findings [7-9, 12, 15, 21, 22, 26]. The results of these comparative studies

158   have significant quantitative discrepancies, but a fundamental qualitative conclusion

159   recurs; no single SLAP lesion test has the sensitivity or specificity to independently

160   determine the presence or absence of a SLAP lesion [7-9, 25]. Although previous studies

161   assess the diagnostic accuracy of specific SLAP lesion tests, they do little to explain the

162   reasons behind their apparent failure and rarely suggest or point to any means of

163   improving the performance of the tests.

164   Clinically based evaluations of SLAP lesion tests account for the majority of

165   studies to date; however, studies have also assessed test accuracy by attempting to

166   validate the fundamental design behind various SLAP lesion tests [11, 16, 27, 32]. Provocative

167   SLAP lesion tests, by definition, function to provoke labral symptoms (primarily pain) as

168 a positive diagnostic sign, by reenacting one of two injury mechanisms. The first

169 mechanism elicits active tension in the biceps tendon and is typically associated with an

170 acute traction trauma to the arm or from the accumulation of microtrauma events over

171 time from repetitive movements such as overhead throwing. The tensile load produced in

172 the biceps tendon can pull and damage the superior labrum, the functional link between

173 the insertion of the biceps tendon and the glenoid rim. The second injury mechanism

174 produces passive compression of the humeral head and is often associated with a fall to

175 outstretched arms. The compressive load causes superior humeral head translation within

176 the glenohumeral joint and can result in a collision between the humerus and labrum,

177 potentially damaging the soft tissue of the labrum [1]. The ability of proposed SLAP lesion

178 tests to reenact the injury mechanisms that they were designed to replicate has been

179 examined from several perspectives including anatomic [11, 16, 27], kinematic [20], and

180 electromyographic [11, 32] methods and results illuminate the importance of design

181 validation during the development of clinical testing procedures.

182 The purpose of this study was to assess the ability of seven provocative tests to

183 create active tension in the biceps tendon, by characterizing the behaviors of

184 glenohumeral joint stabilizing muscles, with particular interest in the long head of the

185 biceps brachii (LHBB) muscle activation and LHBB muscle selectivity. Tests that elicit

186 larger activation of the LHBB should serve as better diagnostic indicators for SLAP

187 lesions. Also the other joint stabilizing muscles were examined to determine individual

188 muscle contributions during the tests, outlining the ability of each test to selectively

189 activate the LHBB. Selectively activating the LHBB should reduce diagnostic

190 complications related to the frequent presence of other confounding pathologies with

191   SLAP lesions.

192   *Materials and Methods.*

193

194   *Subjects and IRB approval*

195   A cohort of 21 healthy volunteers comprised of 11 females (24.7 ± 6.7 years, 168.4

196   ± 5.3cm, 66.9 ± 9.1kg) and 10 males (29.4 ± 10.6 years, 178.1 ± 6.6 cm, 80.0 ±

197   6.4kg) with right arm dominance and no history of shoulder pathology were recruited as

198   subjects in this study. All procedures were approved by the Institutional Review Board at

199   Boise State University, and all participants read and signed a statement of informed

200   consent prior to the start of testing.

201

202   *EMG Apparatus and Subject Preparation and Electrode Placement*

203   Electromyography (EMG) was used to record muscle activity for seven muscles

204   surrounding the dominant glenohumeral joint including the long and short heads of

205   biceps brachii (LHBB and SHBB), anterior deltoid (DELT), pectoralis major (PECT),

206   latissimus dorsi (LAT), infraspinatus (INFRA), and suprasinatus (SUPRA). Each subject

207   was instrumented with one 44-gage fine-wire indwelling electrode and six surface bipolar

208   silver-silver chloride EMG electrodes (Noraxon, USA Inc, Scottsdale, AZ). The surface

209   electrodes were positioned over the muscle belly and parallel with the orientation of the

210   muscle fibers as suggested by Cram [6]. An additional surface electrode was placed on the

211   acromion process of the non-dominant shoulder to serve as a reference. Due to the

212   location of the SUPRA deep to the trapezius, the indwelling electrode was necessary to

213   acquire SUPRA activity. Using sterile techniques, an emergency medical technician who

214   was trained specifically for this task by a medical doctor placed the fine-wire indwelling

215   electrode. EMG data were recorded using the Vicon Nexus Software (Vicon, Los

216   Angelos, CA) at 1250 Hz using a Noraxon Telemyo 900 EMG system (Noraxon USA,

217   Inc, Scottsdale, AZ).

218

219   *EMG Analysis*

220   The EMG signals were analyzed using custom MATLAB software (The

221   MathWorks, Inc, Natick, MA).   A traditional filtering method was used for the EMG

222   signals for the LHBB, SHBB, DELT, PECT, and SUPRA. Each signal was smoothed by

223   implementing a root mean square algorithm in combination with a 20ms forward moving

224   window average. The signals were normalized to a percentage of effort based on their

225   respective Maximum Voluntary Isometric Contraction (MVIC) peak EMG signal

226   amplitudes, ideally resulting in a muscle activation range of zero to 100%. Maximum

227   muscle activation and muscle selectivity were determined for each muscle during each

228   test. The raw data for the DELT and LAT were processed by the same method, but the

229   MVIC peak signals were further examined to ensure that the peak amplitude of the signal

230   did not overlap with a peak from the heartbeat artifacts.

231   Muscle activation and muscle selectivity were calculated to characterize muscle

232   behavior during the provocative tests, with particular interest in the LHBB behavior.

233   Muscle activation was used to determine how effective each SLAP lesion test was at

234   causing individual muscles to activate and was defined as the mean of the peak muscle

235   activities elicited during the three normalized trials. The ability of each provocative test

236   to isolate the LHBB is important for diagnosing SLAP lesions due to its common

237   association with other shoulder pathologies. Therefore in this study, a ratio indicating the

238 ability of each test to selectively activate each muscle was calculated. The muscle

239 selectivity for each test was defined by the ratio of the peak activation of the muscle of

240 interest over the sum of peak activations for all seven muscles examined, such that a

241 selectivity ratio of 1.0 for any muscle, N, would indicate that muscle N was the only

242 active muscle contributing to the EMG signal while the other six muscles remained

243 inactive. For each test the general selectivity calculation for muscle N was defined as:

244 $$N \_ SelectivityRatio = \frac{A_N}{A_{LHBB} + A_{SHBB} + A_{DELT} + A_{PECT} + A_{LAT} + A_{INFRA} + A_{SUPRA}}$$

245 N is the muscle of interest (LHBB, SHBB, DELT, PECT, LAT, INFRA, or SUPRA)

246 $N \_ SelectivityRatio$ is the selectivity ratio of muscle N

247 A_N is the peak muscle activation of muscle N

248

249 *Subject Protocol – MVICs and Provocative Tests*

250   Using established EMG protocols, each subject was asked to perform MVICs for

251 each muscle of interest on a Biodex System II Dynamometer (Biodex Medical Systems,

252 Shirly, NY). Modifications were made to the MVIC recommendations of Cram,

253 Hintermeister, and Rowlands [6, 13, 29] to accommodate for the use of the Biodex system

254 [Table I]. For each trial, six seconds of data were recorded to ensure that the entire burst

255 of muscle activity was captured during each MVIC. The subjects performed three trials

256 for each MVIC and were asked to maximally contract for a count of three seconds.

257 Subjects rested for thirty seconds between MVIC trials to avoid fatigue effects. For each

258 MVIC, the peak amplitude of the EMG signal among the three trials was used to

259 normalize the provocative test data.

260   Similarly seven provocative tests were performed based on the descriptions of the

261   original authors but with modifications to accommodate for use of the Biodex System.

262   These tests were chosen based on the findings of a preliminary pilot study that evaluated

263   clinical tests from relevant literature that were designed to reenact either SLAP lesion

264   injury mechanism [20].   Again the subject performed three trials for a three second count

265   for each test, six seconds of data were recorded for each trial, and the subjects rested for

266   thirty seconds between trials.

267

268   *Provocative Test Descriptions and Study Modifications*

269   The modifications for each MVIC and six of the seven SLAP lesion tests utilized the

270   Biodex System for the purpose of reducing the influence of variances in muscle behavior

271   and test performance. Tests requiring static resistance against an applied load maintained

272   the static subject position through the stationary preset up of the Biodex System. Tests

273   requiring dynamic resistance to an applied load were controlled by the Biodex System

274   allowing a constant velocity regardless of the force applied by the subject.

275

276   <u>Active Compression Test (ACPD and ACPU)</u>

277   Active Compression has two positions, palm down (ACPD) and palm up (ACPU),

278   which vary only by rotation of the arm. The patient is standing with the elbow in full

279   extension, the shoulder is flexed to 90°, and adducted $10-15^\circ$ medial to the sagittal

280   plane. For ACPD, the forearm is fully pronated and the glenohumeral joint is

281   maximally internally rotated such that the thumb points down. The patient is asked to

282   resist a uniform downward load applied to their arm by the clinician. For ACPU the

283   initial patient positioning is unchanged except the arm is externally rotated such that

284   the palm faces up. Again, the patient is asked to resist a uniform downward load

285   applied by the clinician [24].

286   For the purpose of analysis and due to the nature of the subject population as a

287   control group having no history of shoulder pathology and therefore asymptomatic,

288   this study treated ACPU and ACPD as two independent tests. Both tests were

289   modified such that the subject was seated in the Biodex. The orientation of the

290   subject's arm remained true to O'Brien's original description of the test, but the

291   subject was asked to resist the stationary position of the Biodex arm by attempting to

292   lift his/her arm superiorly for both ACPD and ACPU.

293

294   Speed's Test (Speed's)

295   According to the original description, the patient is standing and resists a

296   downward force applied to the upper extremity with the elbow extended, forearm

297   supinated, and arm elevated to 90° [2]. In this study the orientation of the arm remained

298   similar to the original definition, but Speed's test was modified into a dynamic

299   movement controlled by the Biodex System. The subject's arm started hanging

300   beside and parallel to the body, and then the subject was asked to raise the arm (flex

301   the shoulder) with as much force as possible to 90°. Regardless of the force applied

302   by the subject, motion was restricted to a constant velocity by the Biodex System of

303   60° per second.

304

305   Pronated Load Test (ProLoad)

306   In the original description, the patient is in the seated position with elbow flexed

307   to 90°, the arm is abducted to 90°, maximally externally rotated, and the forearm is

308   fully pronated. The patient is then asked to perform an isometric contraction of the

309   Biceps [33]. The Pronated Load Test was negligibly modified for this study. The

310   subject sat in the original orientation in the Biodex System, which was set up such

311   that the arm was supported just proximal to the elbow. The subject was asked to

312   perform a bicep contraction (pronated curl) which was resisted by the static set up of

313   the Biodex System.

314

315   Biceps Load I Test (Bicep I)

316   The patient is in the supine position when an anterior apprehension test is

317   performed starting with the arm abducted 90° and the forearm fully supinated

318   according to its original definition[19]. Bicep I was modified such that the patient was

319   seated in the same position as ProLoad, except the forearm was fully supinated. The

320   subject was asked to perform a bicep contraction (curl), which was resisted by the

321   static set up by the Biodex System.

322

323   Biceps Load II Test (Bicep II)

324   The patient is supine with the arm abducted to 120° degrees, the elbow flexed to

325   90° degrees, and the forearm fully supinated. The patient is then asked to flex the

326   elbow against the resistance of the clinician [18]. For this study the modification for

327   Bicep II paralleled those made to Bicep I except the arm was abducted to

328   120° degrees instead of 90°.

329

330   Resisted Supination External Rotation Test (RSER)

331   The authors describe putting the patient in the supine position with scapula near

332   the edge of the table, the patients arm is supported by the physician at the wrist, with

333   the arm is abducted to $90°$ and the elbow is flexed between $65°$ and $70°$ degrees. The

334   clinician then externally rotates the arm while the patient is asked to supinate the

335   forearm [23]. The RSER test was essentially unchanged for this study, and the

336   movement was not controlled by the Biodex System. One board certified athletic

337   trainer performed RSER with each subject in the study in the supine position on the

338   Biodex.

339

340   Supination Sign Test (Yergason's)

341   In the seated position with the elbow flexed to $90°$ and forearm fully pronated,

342   the patient is asked to attempt supination of the forearm while the physician resists

343   the motion while holding the wrist [34]. Yergason's was scarcely modified; as the

344   patient maintained the defined orientation but with the forearm fastened to the static

345   Biodex arm. The patient was asked to attempt to supinate the forearm against the

346   static setup of the Biodex.

347

348   *Statistical Analysis*

349   Statistical analysis was conducted using SPSS Statistics Software (SPSS, Inc,

350   Chicago, IL) to determine significant differences in maximum muscle activations and

351   muscle selectivities for each test, between tests, and between male and female groups. A

352   repeated measures analysis of variance (ANOVA) test was performed to identify

353   significant differences between provocative tests for each individual muscle. A pair-wise

354   T-test post-hoc analysis was performed to compare results between each test using a p-

355   value sliding scale Bonferroni adjustment [14]. Likewise, a paired-sample T-test was used

356   to examine potential differences in muscle activation ($p = 0.05$) between male and female

357   groups.

358   *Results*.

359   A post-hoc pair-wise comparison between males and females showed no

360   differences between male and female groups for any muscle or for any provocative test

361   with all p-values exceeding 0.05. Therefore male and female data were pooled for all

362   subsequent statistical analyses. For each individual muscle, the repeated measures

363   ANOVA analysis found significant differences in both muscle activation and muscle

364   selectivity among the eight provocative tests ($p < .05$).

365   To determine which provocative tests resulted in the greatest activations for the

366   individual muscles, 28 pair-wise comparisons between the eight tests were made for each

367   muscle. Each muscle analyzed showed a significant difference in peak muscle activity

368   between one or more of the pairs of provocative tests with the exception of the LAT.

369   Specifically, the LHBB demonstrated a significant difference ($p=.000$) in activity

370   between tests. The eight statistically significant pair-wise comparisons enabled the tests

371   to be characterized into one of two performance groups based on their respective LHBB

372   activation; high performing and low performing. Speed's, ACPU, Bicep I, and Bicep II,

373   tests were 'high performing', eliciting the largest mean peak EMG amplitudes without

374   statistical differences among the four tests, while RSER, Yergason's, ACPD, and

375   ProLoad were classified as 'low performing' (Figure 2). The mean normalized peak

376   activations (% MVIC) for each muscle elicited during all eight tests are noted in Table II.

377   The statistical analysis with regards to muscle selectivity for each test proved

378   similar to those for muscle activation. There were significant differences in muscle

379   selectivity across the provocative tests ($p=.000$). A post-hoc pair-wise comparison

380   showed that one or more pairs of tests had significant differences in muscle selectivity for

381   each muscle with the exception of the LAT and INFRA. The eleven statistically

382   significant pairs allowed the tests to be categorized into high and low performance groups

383   based on LHBB selectivity. RSER, Bicep I, Bicep II, and Yergason's tests were 'high

384   performing', recruiting the LHBB more selectively than ProLoad, Speed's, ACPU, and

385   ACPD, which were categorized as 'low performing' (Figure 3). Again there was no

386   statistical difference among tests within each group. The mean selectivities of each

387   muscle for all eight tests are noted in Table III.

388

389   *Discussion*.

390   The aim of this study was to characterize the muscle behavior of seven

391   glenohumeral joint stabilizing muscles, focusing on the LHBB, during eight modified

392   provocative tests that were designed to detect SLAP lesions by loading the biceps tendon

393   in tension through LHBB activation. The active tension in the biceps tendon is thought to

394   reproduce the injury mechanism of a SLAP lesion, which should provoke a response

395   from suspected SLAP lesion patients yielding a positive diagnostic sign [1, 33]. In this study,

396   Bicep I and Bicep II were the most promising SLAP lesion tests according to their

397   favorable LHBB behavior, eliciting high LHBB activity while remaining highly selective

398   for the LHBB, indicating these two tests should function effectively as assessment tools

399   for the clinical evaluation of SLAP lesions.

400   The magnitude of LHBB activation during each of the clinical evaluations is a

401   measure of the sensitivity of the maneuver to incite active tension in the LHBB tendon

402   which should increase the likelihood of detecting a SLAP tear. Although EMG signal

403   amplitude cannot be directly related to muscle force in most cases, the tests that most

404   strongly activate LHBB should provide relatively higher traction forces to the superior

405   labrum. Speed's, ACPU, Bicep I, and Bicep II tests produced the largest LHBB activities,

406   reaching above 90 % MVIC, suggesting that a greater respective load was applied to the

407   biceps tendon during these tests. Although none of the tests apply loads sufficient to

408   produce a SLAP lesion, Speed's ACPU, Bicep I, and Bicep II tests created the largest

409   LHBB activation and therefore reproduced the injury mechanism more effectively than

410   the other four low-performing tests (RSER, Yergason's, ACPD, and ProLoad). Although

411 SLAP lesion test assessment is prevalent in the literature, comparison between studies is

412 difficult due to the lack of overlap of tests between similar studies. However, two studies

413 support the findings of this study in that ACPU and Bicep II have both been reported to

414 elicit large LHBB EMG amplitudes[11] [32].

415   LHBB selectivity served as an equally important variable to consider for

416 characterizing LHBB behavior and for assessing SLAP lesion tests, as it is an indicator of

417 test specificity. The diagnostic accuracy of SLAP lesion tests are often hindered by the

418 frequent occurrence of other glenohumeral pathologies, such as rotator cuff tears, that

419 make determining the origin of shoulder symptom challenging at best [9, 17, 21, 31].

420 Consequently provocative tests that are able to isolate the LHBB would be beneficial

421 because high LHBB selectivity denotes a lesser contribution from other joint stabilizing

422 muscles that can produce a false SLAP lesion diagnosis. RSER, Bicep I, Bicep II, and

423 Yergason's tests were 'high performing' with regards to selectively recruiting the LHBB.

424 Each high performing test resulted in LHBB selectivity between 0.23 and 0.25, compared

425 to the range of 0.12 and 0.16 selectivity for the 'low performing' tests (Proload, Speeds,

426 ACPU, and ACPD). Unfortunately LHBB selectivity is not reported elsewhere in the

427 relevant literature, but these results concur with the findings of the preliminary pilot study

428 [20].

429   The two overall top performing SLAP lesion tests, Bicep I and Bicep II, elicited

430 large LHBB activation while demonstrating high LHBB selectivity. The clinical

431 implications derived from the remaining tests that were 'high performing' in only a single

432 area of LHBB behavior, either highly specific (activation – ACPU and Speed's) or highly

433 sensitive (selective – RSER and Yergason's), may be limited if used on their own. Top

434 performing SLAP lesion tests, that elicited large LHBB activation and were highly

435 selective for the LHBB, should be closely examined in hopes of defining the

436 characteristics that may be responsible for their promising LHBB behavior.

437   Bicep I and Bicep II are very similar tests, varying only by the flexion of the

438 shoulder joint. Bicep I, Bicep II, Speed's, and ACPU, all of have desirable behavior in

439 one or both suites and may be useful for future work, by examining the clinical

440 implications of these tests in combination. These four tests, Bicep I, Bicep II, Speed's,

441 and ACPU, share similar test and design characteristics relating to location of the applied

442 load, forearm orientation, joint position, and line of pull during either a static or dynamic

443 provocative test designed to activate the LHBB. Each of these tests was performed with

444 a supinated forearm and required active resistance to an external load applied

445 perpendicular to the palm of the subject's hand. Each high performing test was

446 performed in one of two joint positions which placed the LHBB and biceps tendon in a

447 direct line of pull with the superior labrum. The first joint position (Speed's and ACPU)

448 flexed the shoulder to a maximum of $90°$ with the elbow fully extended. The second

449 joint position (Bicep I and Bicep II) had the shoulder abducted at or above $90°$ with the

450 elbow flexed at $90°$. The major difference between these four tests is the way the tests

451 are performed; Speed's is a dynamic test while Bicep I, Bicep II, and ACPU are static

452 tests, where the patient resists the load without the ability to move.

453   In this study ACPU and the Speed's were extremely similar and although both

454 were 'high performing' for LHBB activation, their differences may prove important

455 means of understanding the role and importance of SLAP lesions test characteristics. The

456 tests have slight differences in patient orientation and type of movement; ACPU places

457   the arm medial to the sagittal plane and the test is static, while Speed's is parallel to the

458   medial plane and involves a dynamic movement. These small differences may have

459   important consequences, and a close examination of these kinds of test characteristics and

460   their relation to test performance may help illuminate a means of improving test design

461   and accuracy.

462   Although the focus of this study was the behavior of the LHBB, six other joint

463   stabilizing muscles were recorded to enable LHBB selectivity calculations and in hopes

464   of characterizing any other muscle behaviors or patterns. Peak muscle activities and

465   muscle selectivity were examined for all remaining muscles (SHBB, DELT, PECT, LAT,

466   INFRA, and SUPRA), and statistical analysis revealed that it may be unnecessary to

467   monitor the LAT and INFRA during these tests, because none of the tests had a

468   significant difference in terms of activation of the LAT or in selectively isolating either

469   the LAT or INFRA muscles.

470   The primary inherent limitation of this study is that the subjects had no history of

471   shoulder pathology; therefore labral symptoms were not used as a means to assess SLAP

472   test performance. Also the healthy subject pool may misrepresent SLAP lesion patients

473   due to the potential for differences in muscle behavior between healthy subjects and those

474   with labral pathology. Furthermore, the EMG signals were all normalized based on peak

475   activities elicited during MVIC, and results exceeded 100% in some cases and may make

476   comparison between subjects difficult. Specifically, the dynamic Speed's test, which had

477   the largest mean activation (140.9% MVIC) among the tests, was not a surprising finding,

478   as the dynamic movement was normalized to a static MVIC. Muscle activation is known

479   to vary with both muscle length and shortening or lengthening velocity. Therefore,

480 comparing activation during a dynamic test to data collected in a static configuration may

481 not be optimal. For the static tests, LHBB activations were generally below or much less

482 than that of Speed's, suggesting that the normalization procedure was more appropriate

483 for those tests. However, in some tests subjects were able to achieve more than 100%

484 MVIC in some muscles, which means either that the tests were more effective in isolating

485 those muscles than the MVIC configurations, or that slight differences in positioning or

486 in subject effort in the clinical tests and the MVIC tests affected the muscle activation

487 values recorded.

488 Future studies would improve on the scope of this study by recruiting subjects

489 who have a suspected SLAP lesion and are scheduled for arthroscopic assessment.

490 Employing the methods and results of this study, improvements would utilize the

491 promising LHBB behavior of the top performing modified tests (Bicep I and Bicep II) in

492 conjunction with analyses of associated joint torques. Although joint torque data was

493 not collected in this study due to the inability to acquire torque information for all of the

494 eight modified tests, the top performing SLAP lesions tests are oriented such that the

495 Biodex System could easily provide such information. An analysis of joint torques and

496 associated loads during these tests may further quantify the ability of these tests to create

497 tension in the biceps tendon.

498 Recent studies utilizing arthroscopic verification for clinical evaluations have

499 documented a drastic increase in SLAP lesion detection by using the indications of two or

500 more SLAP tests, specifically when at least one test is highly sensitive and another is

501 highly specific [8, 25]. Consequently, assessing the array of 'high performing' test

502 combinations, utilizing various combinations of single suite high performance tests with

503 various test characteristics may have surprising results and prove worthwhile.

504   Lastly, although difficult to determine and requiring a large pool of control and

505 experimental data, comparisons between the muscle behaviors of a healthy population

506 and those who have a suspected SLAP lesion may illuminate some general pattern

507 differences that could be indicative of SLAP lesions and be useful for furthering clinical

508 diagnostic techniques and accuracy.

509

510   *Conclusions.*

511   In summary, modified versions of Bicep I and Bicep II resulted in the greatest

512   LHBB activation and LHBB selectivity of the SLAP lesion tests in this study. ACPU,

513   and Speed's resulted in the large LHBB activation, but were not selective for the LHBB.

514   Bicep I, Bicep II, ACPU, and Speed's each elicit some promising LHBB behavior, and

515   maybe useful in combination to aid the clinical detection of SLAP lesions. These four

516   tests utilize a unique range of test variables that may prove valuable for optimal SLAP

517   test design and function. Future studies should evaluate the importance of these

518   variables, incorporate joint torque analyses, and expand the scope of the study to include

519   patients who have a suspected SLAP lesion to optimize, validate, and improve the

520   diagnostic accuracy of provocative SLAP lesion test.

526

527

References.

528
529
530
531
532
533
534
535

536   1.   Andrews, J., W. Carson, Jr, and W. McLeod, *Glenoid labrum tears related to the*
537   *long head of the biceps.* Am J Sports Med, 1985. **13**(5): p. 337-341.
538   2.   Bennett, W.F., *Specificity of the Speed's Test: Arthoscopic Technique for*
539   *Evaluating the Biceps Tendon at the Level of the Bicipital Groove.* The Journal of
540   Arthroscopic and Related Surgery, 1998. **14**(8): p. 789-796.
541   3.   Chandnani, V., et al., *Glenoid labral tears: prospective evaluation with MRI*
542   *imaging, MR arthrography, and CT arthrography.* Am. J. Roentgenol., 1993.
543   **161**(6): p. 1229-1235.
544   4.   Chang, D., et al., *SLAP lesions: Anatomy, clinical presentation, MR imaging*
545   *diagnosis and characterization.* European Journal of Radiology, 2008. **68**(1): p.
546   72-87.
547   5.   Chundru, U., *Magnetic Resonance Arthrography.* Musculoskeletal, 2009.
548   6.   Cram, J.R. and G.S. Kasman, *Introduction to surface electromyography.* 1998,
549   Gaithersburg, MD: Aspen Publishers Inc.
550   7.   DaSilva, J.J., A.G. McNickle, and B.J. Cole, *Arthroscopic Superior Labrum*
551   *Anterior to Posterior Repair.* Operative Techniques in Orthopaedics, 2008. **18**(1):
552   p. 53-61.
553   8.   Dessaur, W. and M. Magarey, *Diagnostic accuracy of clinical tests for superior*
554   *labral anterior posterior lesions: a systematic review.* Journal of Orthopaedic and
555   Sports Physical Therapy, 2008. **38**(6): p. 341-352.
556   9.   Gill, H.S., et al., *Physical Examination for Partial Tears of the Biceps Tendon.*
557   Am J Sports Med, 2007. **35**(8): p. 1334-1340.
558   10.   Golay, S.A.M., *'Smoothing and differentiation of data, by simplified least squares*
559   *procedures'.* Analytical Chemistry, 1964. **36**: p. 1627-1639.
560   11.   Green, R.A., et al., *An evaluation of the anatomic basis of the O'Brien active*
561   *compression test for superior labral anterior and posterior (SLAP) lesions.*
562   Journal of Shoulder and Elbow Surgery, 2008. **17**(1): p. 165-171.
563   12.   Guanche, C.A. and D.C. Jones, *Clinical Testing for Tears of the Glenoid Labrum.*
564   The Journal of Arthroscopic and Related Surgery, 2003. **19**(5): p. 517-523.
565   13.   Hintermeister, R.A., et al., *Electromyographic Activity and Applied Load During*
566   *Shoulder Rehabilitation Exercises Using Elastic Resistance.* The American
567   Journal of Sports Medicine, 1998. **26**(2): p. 210-220.
568   14.   Holm, S., *A simple sequentially rejective multiple test procedure.* Scandinavian
569   Journal of Statistics, 1979. **6**: p. 65-70.
570   15.   Holtby, R. and H. Razmjou, *Accuracy of the Speed's and Yergason's Tests in*
571   *Detecting Biceps Pathology and SLAP Lesions: Comparison With Arthroscopic*
572   *Findings.* The Journal of Arthroscopic and Related Surgery, 2004. **20**(3): p. 231-
573   236.

574   16.   Keren J. Shanley, R.A.G., Nicholas F. Taylor,, *An evaluation of the anatomical*
575   *basis of the Biceps Load tests I and II for superior labral anterior and posterior*
576   *(SLAP) lesions.* Clinical Anatomy, 2008. **21**(7): p. 647-651.
577   17.   Kibler, W.B., *Specificity and Sensitivity of the Anterior Slide Test in Throwing*
578   *Athletes With Superior Glenoid Labral Tears.* Arthroscopy, 1995. **11**(3): p. 296-
579   300.
580   18.   Kim, S.-H., et al., *Biceps Load Test II: A Clinical Test for SLAP Lesions of the*
581   *Shoulder.* The Journal of Arthroscopic and Related Surgery, 2001. **17**(2): p. 160-
582   164.
583   19.   Kim, S.-H., K.-I. Ha, and K.-Y. Han, *Biceps Load Test: A Clinical Test for*
584   *Superior Labrum Anterior and Posterior Lesions in Shoulders With Recurrent*
585   *Anterior Dislocations.* The American Journal of Sports Medicine, 1999. **27**(3): p.
586   300-303.
587   20.   Kuhlman, S., Sabick, M, Pfeirffer,, *Biomechanical Evaluation of Physical*
588   *Examination Tests for Superior Labrum Anterior to Posterior (SLAP) Lesions.*
589   Pending Review, 2009.
590   21.   McFarland, E.G., T.K. Kim, and R.M. Savino, *Clinical Assessment of Three*
591   *Common Tests for Superior Labral Anterior-Posterior Lesions.* Am J Sports Med,
592   2002. **30**(6): p. 810-815.
593   22.   Munro, W. and R. Healy, *The validity and accuracy of clinical tests used to detect*
594   *labral pathology of the shoulder â€" A systematic review.* Manual Therapy. **In**
595   **Press, Corrected Proof**.
596   23.   Myers, T.H., J.R. Zemanovic, and J.R. Andrews, *The Resisted Supination*
597   *External Rotation Test: A New Test for the Diagnosis of Superior Labral Anterior*
598   *Posterior Lesions.* The American Journal of Sports Medicine, 2005. **33**(9): p.
599   1315-1320.
600   24.   O'Brien, S.J., et al., *The Active Compression Test: A New and Effective Test for*
601   *Diagnosing Labral Tears and Acromioclavicular Joint Abnormality.* The
602   American Journal of Sports Medicine, 1998. **26**(5): p. 610-613.
603   25.   Oh, J.H., et al., *The Evaluation of Various Physical Examinations for the*
604   *Diagnosis of Type II Superior Labrum Anterior and Posterior Lesion.* Am J
605   Sports Med, 2008. **36**(2): p. 353-359.
606   26.   Parentis, M.A., et al., *An Evaluation of the Provocative Tests for Superior Labral*
607   *Anterior Posterior Tears.* Am J Sports Med, 2006. **34**(2): p. 265-268.
608   27.   Parentis, M.A., et al., *An Anatomic Evaluation of the Active Compression Test.*
609   Journal of Shoulder and Elbow Surgery, 2004. **13**(4): p. 410-416.
610   28.   Robert, D., *Savitsky-Golay Filters.* 2008.
611   29.   Rowlands, L., et al., *Kinesiology of the Empty Can Test.* Am J Phys Med Rehabil,
612   1995. **74**(4): p. 302-304.
613   30.   Snyder, S.J., et al., *SLAP Lesions of the Shoulder.* The Journal of Arthroscopic
614   and Related Surgery, 1990. **6**(4): p. 274-279.
615   31.   Stetson, W.B. and K. Templin, *The Crank Test, the O'Brien Test, and Routine*
616   *Magnetic Resonance Imaging Scans in the Diagnosis of Labral Tears.* Am J
617   Sports Med, 2002. **30**(6): p. 806-809.

618   32.   Swaringen, J.C., et al., *Electromyographic analysis of physical examination tests*
619   *for type II superior labrum anterior-posterior lesions.* Journal of Shoulder and
620   Elbow Surgery, 2006. **15**(5): p. 576-579.
621   33.   Wilk, K.E., et al., *Current Concepts in the Recognition and Treatment of Superior*
622   *Labral (SLAP) Lesions.* Journal of Orthopaedic and Sports Physical Therapy,
623   2005. **35**: p. 273-291.
624   34.   Yergason, R.M., *Supination Sign.* 1995.
625
626

627   **Tables**

628   **Table I**: MVIC joint positions and resisted maneuvers for the seven muscles of interest.

629   **Table II**: Resulting mean normalized peak muscle activations (%MVIC) and standard

630   deviations monitored during each SLAP lesion test.

631   **Table III**: Resulting mean muscle selectivity values and standard deviations monitored

632   during each SLAP lesion test.

633

634

Muscle	Joint Position	Resisted Maneuver
DELT	Arm at side	Shoulder flexion
LHBB / SHBB	Elbow flexed 90°, shoulder flexed 90°	Elbow flexion
INFRA	Arm abducted 45°, elbow flexed 90°	External Rotation
LAT	Shoulder flexed 90°, arm internally rotated	Shoulder extension
PECT	Arm abducted 90°, forearm supinated	Horizontal adduction
SUPRA	Arm abducted 90°, forward flexed 30°, and internally rotated	Maintain against resistance

635

Muscle Peak Mean Activation (% MVIC) and Standard Deviation During SLAP Lesion Tests													
	LHBB		SHBB		DELT		PECT		LAT		INFRA		SUPRA	
ACPD	116.6	(75.2)	86.7	(60.4)	192.1	(97.6)	89.2	(42.8)	116.2	(161.6)	182.3	(174.8)	84.8	(38.6)
ACPU	74.9	(66.4)	15.7	(12.8)	116.7	(65.7)	28.4	(17.5)	93.8	(146.3)	110.1	(82.9)	105.4	(62.7)
Speeds	140.9	(100.9)	104.2	(90.6)	158.4	(72.0)	88.0	(35.4)	124.1	(158.4)	143.3	(96.4)	107.7	(58.5)
Bicep I	97.6	(37.2)	88.9	(36.5)	43.9	(49.4)	36.0	(20.0)	72.6	(65.4)	56.8	(58.9)	26.7	(22.5)
Bicep II	94.0	(48.0)	88.7	(42.8)	49.8	(56.9)	44.8	(21.8)	56.2	(46.4)	41.9	(37.9)	30.7	(43.1)
ProLoad	58.1	(32.8)	39.8	(19.0)	58.9	(49.5)	28.5	(15.9)	70.1	(60.4)	69.2	(53.7)	39.4	(31.1)
RSER	89.2	(65.7)	85.6	(65.0)	15.4	(17.4)	23.5	(19.5)	49.5	(32.6)	59.2	(61.1)	25.9	(22.5)
Yergasons	81.1	(46.3)	81.6	(52.0)	22.3	(19.1)	31.8	(19.9)	98.4	(152.8)	56.3	(50.4)	24.1	(19.7)

636

637

Muscle Mean Selectivity and Standard Deviation During SLAP Lesion Tests													
	LHBB		SHBB		DELT		PECT		LAT		INFRA		SUPRA	
ACPD	0.132	(0.056)	0.118	(0.059)	0.300	(0.104)	0.225	(0.139)	0.268	(0.203)	0.633	(0.145)	0.105	(0.049)
ACPU	0.122	(0.091)	0.034	(0.032)	0.259	(0.118)	0.102	(0.074)	0.264	(0.178)	0.494	(0.200)	0.213	(0.122)
Speeds	0.152	(0.065)	0.138	(0.066)	0.263	(0.076)	0.209	(0.076)	0.283	(0.214)	0.566	(0.182)	0.131	(0.064)
Bicep I	0.244	(0.079)	0.308	(0.124)	0.188	(0.134)	0.229	(0.110)	0.479	(0.206)	0.587	(0.230)	0.064	(0.055)
Bicep II	0.231	(0.070)	0.303	(0.113)	0.217	(0.135)	0.293	(0.146)	0.452	(0.188)	0.558	(0.281)	0.072	(0.082)
ProLoad	0.160	(0.069)	0.144	(0.078)	0.204	(0.124)	0.150	(0.078)	0.401	(0.252)	0.602	(0.220)	0.113	(0.087)
RSER	0.255	(0.086)	0.336	(0.136)	0.092	(0.080)	0.164	(0.106)	0.415	(0.229)	0.636	(0.203)	0.075	(0.047)
Yergasons	0.225	(0.086)	0.311	(0.158)	0.104	(0.063)	0.186	(0.086)	0.427	(0.226)	0.653	(0.189)	0.067	(0.044)

638

639

640   **Illustrations and Legends**

641   **Figure 1:** Example of Biodex System modifications, ACPD and ACPU.

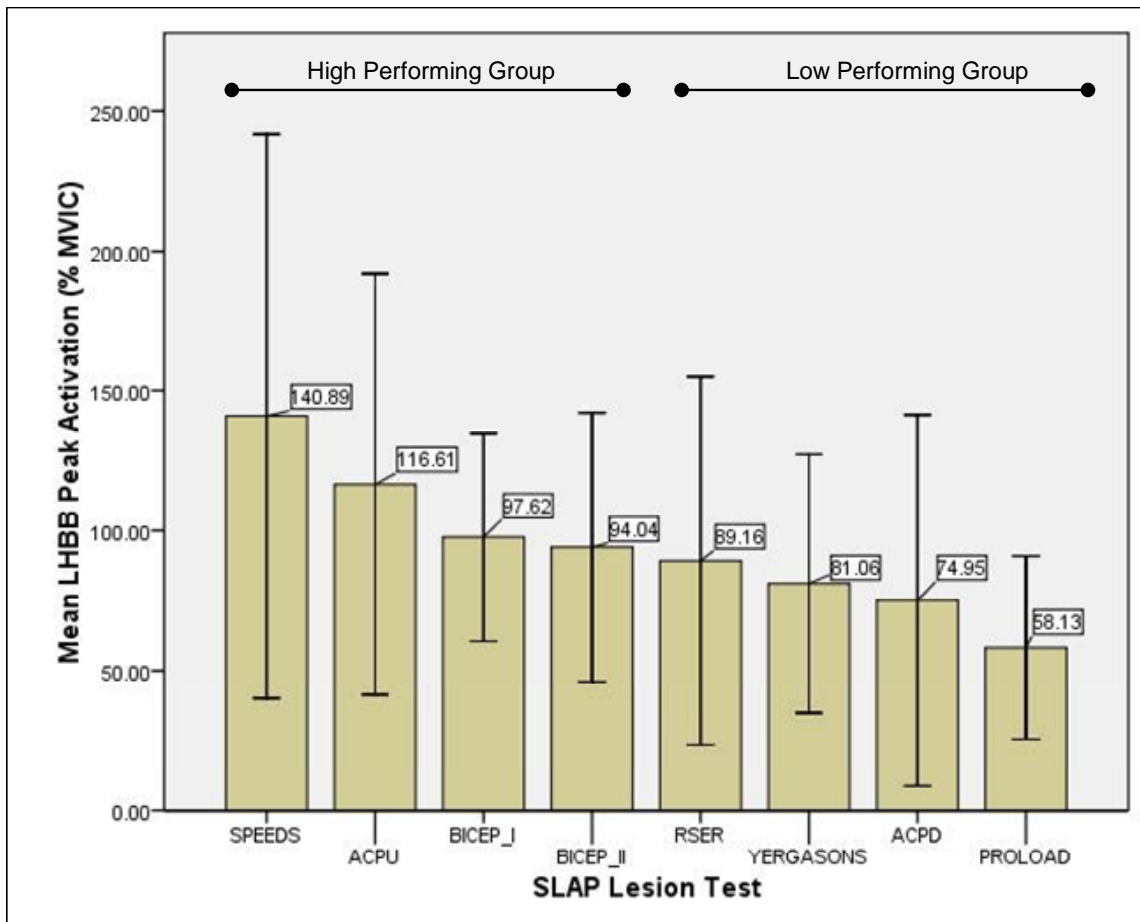642   **Figure 2:** LHBB mean muscle activation (%MVIC) for each SLAP test.

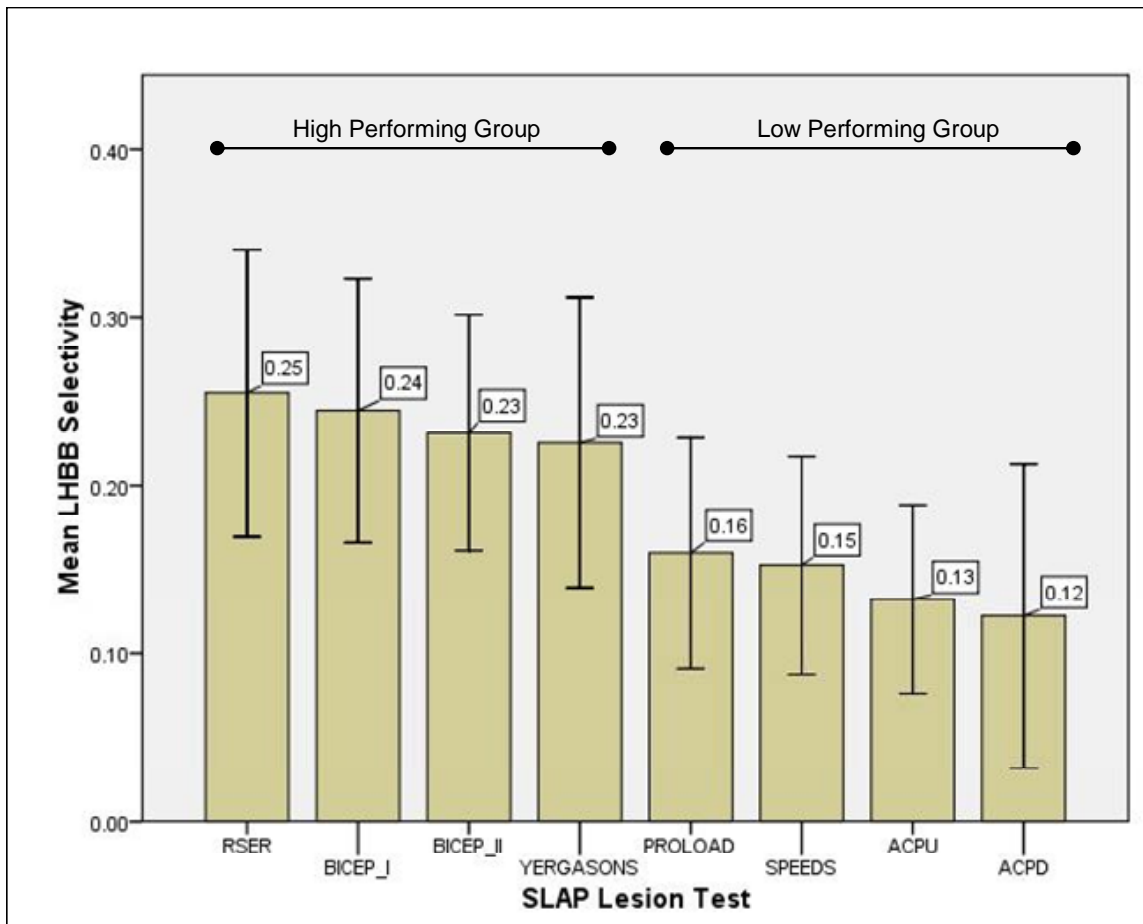643   **Figure 3:** LHBB mean muscle selectivity for each SLAP test.

644

645
646
647
648
649
650
651
652
653
654
655
656

657

658

659