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GLENOHUMERAL MUSCLE ACTIVATION DURING PROVOCATIVE TESTS DESIGNED TO DIAGNOSE SUPERIOR LABRUM ANTERIOR-POSTERIOR LESIONS

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Abstract

Background—Despite considerable medical advances, arthroscopy remains the only definitive means of Superior Labrum Anterior-Posterior (SLAP) lesion diagnosis. Natural shoulder anatomic variants limit the reliability of radiographic findings and clinical evaluations are not consistent. Accurate clinical diagnostic techniques would be advantageous due to the invasiveness, patient risk, and financial cost associated with arthroscopy.

Purpose—The purpose was to examine the behavior of the joint stabilizing muscles in provocative tests for SLAP lesions. Electromyography was used to characterize the muscle behavior, with particular interest in the long head biceps brachii (LHBB), as activation of the long head and subsequent tension in the biceps tendon should, based on related research, elicit labral symptoms in SLAP lesion patients.

Study Design—Controlled Laboratory Study

Methods—Volunteers (N=21) without a history of shoulder pathology were recruited. The tests analyzed were Active Compression, Speed's, Pronated Load, Biceps I, Biceps II, Resisted Supination External Rotation, and Yergason's. Tests were performed with a dynamometer to improve reproducibility. Muscle activity was recorded for the long and short heads of the biceps brachii, anterior deltoid, pectoralis major, latissimus dorsi, infraspinatus, and supraspinatus. Muscle behavior for each test was characterized by peak activation and proportion of muscle activity.

Results—Speed's, Active Compression Palm-Up, Bicep I and Bicep II, produced higher long head activations. Resisted Supination External Rotation, Bicep I, Bicep II, and Yergason's, produced a higher LHBB proportion.

Conclusion—Bicep I, and Bicep II elicited promising long head behavior (high activation and selectivity). Speed's and Active Compression Palm-Up elicited higher activation of the LHBB, and Resisted Supination and Yergason's elicited selective LHBB activity. These top performing tests utilize a unique range of test variables that may prove valuable for optimal SLAP test design and performance.

Clinical Relevance—This study examines several provocative tests that are frequently used in the clinical setting as a means of evaluating a potential SLAP lesion.

[Review Only] What is known about the subject—Detecting SLAP lesions in the clinical setting has been frequently examined in the relevant literature. In general, most studies report the

accuracy of a SLAP lesion test after a group of patients with suspected SLAP lesions are diagnosed following arthroscopy, and very few of these studies have examined the biomechanical implications of these tests.

[Review Only] What this study adds to existing knowledge—To the best of the authors' knowledge this is the first study to examine these seven provocative test in parallel and in subjects with no history of shoulder pathology. Again, to the best of the authors' knowledge this study is also the first to examine both activation and selectivity of the long head of the biceps and six other joint stabilizing muscles. In this study, subjects performed each test with a Biodex System to improve uniformity between subject positions and force discrepancies.

Keywords

SLAP; Superior Labrum Anterior Posterior Lesion; provocative test; long head biceps brachii; diagnoses; electromyography

Introduction

The advent of shoulder arthroscopy as a medical tool led to the description of glenoid labral tears in 1985¹, and superior labrum anterior-posterior tears were coined 'SLAP lesions' in 1990²⁸. Although it has been almost two decades since SLAP lesions were defined, diagnosis remains difficult^{16, 20, 29} despite considerable advances in the understanding of glenohumeral biomechanics and glenoid labral pathologies. In spite of these advances, arthroscopy remains the only definitive means of SLAP lesion detection^{4, 8}. Accurate clinical diagnostic techniques, as an alternative to shoulder arthroscopy, would be advantageous due to the invasiveness, financial cost, and patient risk associated with arthroscopy.

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. Though radiography, particularly MR arthrography in high contrast, has shown some promise as a supplementary tool in SLAP lesion diagnosis, natural anatomic variants limit the reliability of all radiographic diagnoses. Furthermore, parallel to arthroscopy, radiography can be invasive, expensive, and dangerous, causing life threatening allergic reactions⁵ in some patients, rendering radiography an imperfect means of SLAP lesion detection^{3, 4, 7}.

More than 20 provocative tests for the clinical evaluation of SLAP lesions are proposed in the literature. In most cases, the evaluation of the physical exams by the original authors reveals promising accuracy for the detection of SLAP lesions^{2, 17, 18, 22, 23, 32}. However, secondary studies often fail to reproduce the initial findings, typically reporting much lower values for the sensitivity and specificity of the physical examination tests^{8, 11, 14, 20, 24, 25, 31}. The discrepancies between the findings 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 symptoms³, and 2) differences in study protocols and problems associated with the methods used to verify accuracy of the physical examinations make comparisons between studies difficult⁸.

The bulk of the literature assesses SLAP lesion tests by determining diagnostic accuracy through 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 test is then verified with conclusive arthroscopic findings^{7-9, 11, 14, 20, 21, 25}. 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, 24}. Although previous studies assess the diagnostic accuracy of specific SLAP lesion tests, they 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.

Clinically based evaluations of SLAP lesion tests account for the majority of studies to date; however, studies have also assessed test accuracy by attempting to validate the fundamental design behind various SLAP lesion tests^{10, 15, 26, 30}. Provocative SLAP lesion tests, by definition, function to provoke labral symptoms (primarily pain) as a positive diagnostic sign, by reenacting one of two injury mechanisms. The first mechanism elicits active tension in the long head biceps brachii (LHBB) tendon and is typically associated with an acute traction trauma to the arm or from the accumulation of microtrauma events over time from repetitive movements such as overhead throwing. 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. 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 labrum¹. The ability of proposed SLAP lesion tests to reproduce the injury mechanisms that they were designed to replicate has been examined from several perspectives including anatomic^{10, 15, 26}, kinematic¹⁹, and electromyographic^{10, 30} methods and results illuminate the importance of design validation during the development of clinical testing procedures.

The purpose of this study was to assess the ability of eight provocative tests to create active tension in the biceps tendon, by characterizing the behaviors of glenohumeral joint stabilizing muscles, with particular interest in the long head of the biceps brachii (LHBB) muscle activation and LHBB muscle selectivity. Tests that elicit larger activation of the LHBB should serve as better diagnostic indicators for SLAP lesions. Other joint stabilizing muscles were also examined to determine individual muscle contributions during the tests, outlining the ability of each test to selectively activate the LHBB. Selectively activating the LHBB should reduce diagnostic complications related to the frequent presence of other confounding pathologies with SLAP lesions.

Materials and Methods

Subjects and IRB approval

A cohort of 21 healthy volunteers comprised of 11 females (24.7 ± 6.7 years, 168.4 ± 5.3 cm, 66.9 ± 9.1 kg) and 10 males (29.4 ± 10.6 years, 178.1 ± 6.6 cm, 80.0 ± 6.4 kg) with right arm dominance and without any pre-existing shoulder pathologies were recruited as subjects for this study. Screening of the subjects was based on verbal confirmation of no shoulder pathology; a diagnostic evaluation was not conducted. All procedures were approved by the Institutional Review Board and all participants read and signed a statement of informed consent prior to the start of testing.

EMG Apparatus and Subject Preparation and Electrode Placement

Electromyography (EMG) was used to record muscle activity for seven muscles surrounding the dominant glenohumeral joint including the long and short heads of biceps brachii (LHBB and SHBB), anterior deltoid (DELTA), pectoralis major (PECT), latissimus dorsi (LAT), infraspinatus (INFRA), and supraspinatus (SUPRA). Each subject was instrumented with one 44-gage 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 suggested by Cram⁶. 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, an emergency medical technician who was trained specifically for this task by a medical doctor placed the fine-wire indwelling electrode. EMG data were recorded using the Vicon Nexus Software (Vicon, Los Angeles, CA) at 1250 Hz using a Noraxon Telemetry 900 EMG system (Noraxon USA, Inc, Scottsdale, AZ).

EMG Analysis

The EMG signals were analyzed using custom MATLAB software (The MathWorks, Inc, Natick, MA). A traditional filtering method was used for the EMG signals for the LHBB, SHBB, DELT, PECT, and SUPRA. Each signal was smoothed by implementing a root mean square algorithm in combination with a 20ms forward moving window average. The signals were normalized to a percentage of effort based on their respective Maximum Voluntary Isometric Contraction (MVIC) peak EMG signal amplitudes, ideally resulting in a muscle activation range of zero to 100%. Maximum normalized muscle activation selectivity were determined for each muscle during each test. The raw data for the DELT and LAT were processed by the same method, but the MVIC peak signals were further examined to ensure that the peak amplitude of the signal did not overlap with a peak from the heartbeat artifacts.

Muscle activation and muscle selectivity were calculated to characterize muscle behavior during the provocative tests, with particular interest in the LHBB behavior. Muscle activation was used to determine how effective each SLAP lesion test was at causing individual muscles to activate and was defined as the mean of the peak normalized muscle signals elicited during the three trials. The ability of each provocative test to isolate the LHBB is important for diagnosing SLAP lesions due to its common association with other shoulder pathologies. Therefore in this study, a ratio indicating the ability of each test to selectively activate each muscle was calculated. The muscle selectivity for each test was defined by the ratio of the peak normalized activation of the muscle of interest over the sum of peak normalized activations for all seven muscles examined, such that 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 general selectivity calculation for muscle N was defined as:

$$N_SelectivityRatio = \frac{A_N}{A_{LHBB} + A_{SHBB} + A_{DELT} + A_{PECT} + A_{LAT} + A_{INFRA} + A_{SUPRA}}$$

- $N_SelectivityRatio$ is the selectivity ratio of muscle N
- N is the muscle of interest (LHBB, SHBB, DELT, PECT, LAT, INFRA, or SUPRA)
- A_N is the peak normalized muscle activation of muscle N

Subject Protocol – MVICs and Provocative Tests

Using established EMG protocols, each subject was asked to perform MVICs for each muscle of interest on a Biodex System II Dynamometer (Biodex Medical Systems, Shirley, NY). Modifications were made to the MVIC recommendations of Cram, Hintermeister, and Rowlands^{6, 12, 27} to accommodate for the use of the Biodex system [Table I]. 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.

Similarly seven provocative tests were performed 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 either SLAP lesion injury mechanism¹⁹. Again the 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.

Provocative Test Descriptions and Study Modifications

The modifications for each MVIC and six of the seven SLAP lesion tests utilized the Biodex System for the purpose of reducing the influence of variances in muscle behavior and test performance. Tests requiring static resistance against an applied load maintained the static subject position through the stationary preset up of the Biodex System. Tests requiring dynamic resistance to an applied load were controlled by the Biodex System allowing a constant velocity regardless of the force applied by the subject. Images of each test setup are shown in Figure 1.

Active Compression Test (ACPD and ACPU)—Active Compression has two positions, palm down (ACPD) and palm up (ACPU), which vary only by 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, the forearm is fully pronated and the glenohumeral joint 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 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 clinician²³.

For the purpose of analysis and due to the nature of the subject population as a control group having no history of shoulder pathology and therefore asymptomatic, this study treated ACPU and ACPD as two independent tests. Both tests were modified such that the subject was seated in the Biodex. The orientation of the subject's arm remained true to O'Brien's original description of the test, but the subject was asked to resist the stationary position of the Biodex arm by attempting to lift his/her arm superiorly for both ACPD and ACPU.

Speed's Test (Speed's)—According to the original description, 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 arm remained similar to the original definition, but Speed's test was performed dynamically mimicking a variation of the original test which is commonly referred to as the “dynamic Speed's test”.³¹ The subject's arm started hanging beside and parallel to the body, 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 applied by the subject, motion was restricted to a constant velocity by the Biodex System of 60° per second.

Pronated Load Test (ProLoad)—In the original description, the patient is in the seated position with elbow flexed to 90°, the arm is abducted to 90°, maximally externally rotated, and the forearm is fully pronated. The patient is then asked to perform an isometric contraction of the Biceps³¹. The Pronated Load Test was negligibly modified for this study. The subject sat in the original orientation in the Biodex System, which was set up such that the 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.

Biceps 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°, elbow flexed 90°, and the forearm fully supinated according to its original definition¹⁸. Bicep I was modified such that the patient was seated in the same position as ProLoad, except the forearm was fully supinated. The subject was asked to perform a bicep contraction (curl), which was resisted by the static set up by the Biodex System.

Biceps Load II Test (Bicep II)—The patient is supine with the arm abducted to 120° degrees, the elbow flexed to 90° degrees, and the forearm fully supinated. The patient is then asked to flex the elbow against the resistance of the clinician¹⁷. For this study the modification for Bicep II paralleled those made to Bicep I except the arm was abducted to 120° degrees instead of 90°.

Resisted Supination External Rotation Test (RSER)—The authors describe putting the patient in the supine position with scapula near the edge of the table, the patients arm is supported by the physician at the wrist, with the arm is abducted to 90° and the elbow is flexed between 65° and 70° degrees. The clinician then externally rotates the arm while the patient is asked to supinate the forearm²². The RSER test was unchanged for this study. A licensed athletic trainer performed RSER with each subject in the supine position using the Biodex only as an exam table.

Supination Sign Test (Yergason's)—In the seated position with the elbow flexed to 90° and forearm fully pronated, the patient is asked to attempt supination of the forearm while the physician resists the motion while holding the wrist³². Yergason's was scarcely modified; the patient maintained the defined orientation but with the forearm fastened to the static Biodex arm. The patient was asked to attempt to supinate the forearm against the static setup of the Biodex while maintaining the specified elbow and shoulder position.

Statistical Analysis—Statistical analysis was conducted using SPSS Statistics Software (SPSS, Inc, Chicago, IL) to determine significant differences in maximum muscle activations and muscle selectivities for each test, between tests, and between male and female groups. An a priori power analysis was conducted based on previous research and a minimum sample size of 20 subjects was determined. 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 adjustment¹³. Likewise, a paired-sample T-test was used to examine potential differences in muscle activation ($p = 0.05$) between male and female groups.

Results

A post-hoc pair-wise comparison between males and females showed no differences between male and female groups for any muscle or for any provocative test with all p-values exceeding 0.05. Therefore male and female data were pooled for all subsequent statistical analyses. For each individual muscle, the repeated measures ANOVA analysis found significant differences in both muscle activation and muscle selectivity among the eight provocative tests ($p < .05$).

To determine which provocative tests resulted in the greatest activations for the individual muscles, 28 pair-wise comparisons between the eight tests were made for each muscle. Each muscle analyzed showed a significant difference in peak muscle activity between one or more of the pairs of provocative tests with the exception of the LAT. Specifically, the LHBB demonstrated a significant difference ($p=.000$) in activity between tests. The eight

statistically significant pair-wise comparisons enabled the tests to be characterized into one of two performance groups based on their respective LHBB activation; high performing and low performing. Speed's, ACPU, Bicep I, and Bicep II, tests were 'high performing', eliciting the largest mean peak normalized EMG amplitudes without statistical differences among the four tests, while RSER, Yergason's, ACPD, and ProLoad were classified as 'low performing' (Figure 2). The mean normalized peak activations (% MVIC) for each muscle elicited during all eight tests are noted in Table II.

The statistical analysis with regards to muscle selectivity for each test proved similar to those for muscle activation. There were significant differences in muscle selectivity across the provocative tests ($p=.000$). A post-hoc pair-wise comparison showed that one or more pairs of tests had significant differences in muscle selectivity for each muscle with the exception of the LAT and INFRA. The eleven statistically significant pairs allowed the tests to be categorized into high and low performance groups based on LHBB selectivity. RSER, Bicep I, Bicep II, and Yergason's tests were 'high performing', recruiting the LHBB more selectively than ProLoad, Speed's, ACPU, and ACPD, which were categorized as 'low performing' (Figure 3). Again there was no statistical difference among tests within each group. The mean selectivities of each muscle for all eight tests are noted in Table III.

Discussion

The aim of this study was to characterize the muscle behavior of seven glenohumeral joint stabilizing muscles, focusing on the LHBB, during eight modified provocative tests that were designed to detect SLAP lesions by loading the biceps tendon in tension through LHBB activation. The active tension in the biceps tendon is thought to reproduce the injury mechanism of a SLAP lesion, which should provoke a response from suspected SLAP lesion patients yielding a positive diagnostic sign^{1, 31}. In this study, Bicep I and Bicep II were the most promising SLAP lesion tests according to their favorable LHBB behavior, eliciting high LHBB activity while remaining highly selective for the LHBB, indicating these two tests should function effectively as assessment tools for the clinical evaluation of SLAP lesions.

The magnitude of LHBB activation during each of the clinical evaluations is a measure of the sensitivity of the maneuver to incite active tension in the LHBB tendon which should increase the likelihood of detecting a SLAP tear. Although EMG signal amplitude cannot be directly related to muscle force in most cases, the tests that most strongly activate LHBB should provide relatively higher traction forces to the superior labrum. Speed's, ACPU, Bicep I, and Bicep II tests produced the largest LHBB activities, reaching above 90 % MVIC, suggesting that a greater respective load was applied to the biceps tendon during these tests. Although none of the tests apply loads sufficient to produce a SLAP lesion, Speed's ACPU, Bicep I, and Bicep II tests created the largest LHBB activation and therefore reproduced the presumed injury mechanism more effectively than the other four low-performing tests (RSER, Yergason's, ACPD, and ProLoad). Although SLAP lesion test assessment is prevalent in the literature, comparison between studies is difficult due to the lack of overlap of tests between similar studies. However, two studies support the findings of this study in that ACPU and Bicep II have both been reported to elicit large LHBB EMG amplitudes^{10,30}.

LHBB selectivity served as an equally important variable to consider for characterizing LHBB behavior and for assessing SLAP lesion tests, as it is an indicator of test specificity. The diagnostic accuracy of SLAP lesion tests are often hindered by the frequent occurrence of other glenohumeral pathologies, such as rotator cuff tears, that make determining the origin of shoulder symptom challenging at best^{9, 16, 20, 29}. Consequently provocative tests

that are able to isolate the LHBB would be beneficial because high LHBB selectivity denotes a lesser contribution from other joint stabilizing muscles that can produce a false-positive SLAP lesion diagnosis. RSER, Bicep I, Bicep II, and Yergason's tests were 'high performing' with regards to selectively recruiting the LHBB. Each high performing test resulted in LHBB selectivity between 0.23 and 0.25, compared to the range of 0.12 and 0.16 selectivity for the 'low performing' tests (Proload, Speeds, ACPU, and ACPD). Unfortunately LHBB selectivity is not reported elsewhere in the relevant literature, but these results concur with the findings of the pilot study.¹⁹

The two overall top performing SLAP lesion tests, Bicep I and Bicep II, elicited large LHBB activation while demonstrating high LHBB selectivity. The clinical implications derived from the remaining tests that were 'high performing' in only a single area of LHBB behavior, either highly specific (activation – ACPU and Speed's) or highly sensitive (selective – RSER and Yergason's), may be limited if used on their own. Top performing SLAP lesion tests, that elicited large LHBB activation and were highly selective for the LHBB, should be closely examined in hopes of defining the characteristics that may be responsible for their promising LHBB behavior.

Bicep I and Bicep II are very similar tests, varying only by the amount of abduction of the shoulder joint. Bicep I, Bicep II, Speed's, and ACPU, all have desirable behavior in one or both measures of muscle activation. Based on our results, future studies should examine whether these tests would be more efficacious when used in combination. All four tests, share similar design characteristics relating to location of the applied load, forearm orientation, joint position, and line of pull during either a static or dynamic provocative test designed to activate the LHBB. Each of these tests was performed with a supinated forearm and required active resistance to an external load applied perpendicular to the palm of the subject's hand. Each high performing test was performed in one of two joint positions which placed the LHBB and biceps tendon in a direct line of pull with the superior labrum. The first joint position (Speed's and ACPU) flexed the shoulder to a maximum of 90° with the elbow fully extended. The second joint position (Bicep I and Bicep II) had the shoulder abducted at or above 90° with the elbow flexed at 90°. The major difference among these four tests is the way the tests are performed; Speed's, as performed by many clinicians, is a dynamic test while Bicep I, Bicep II, and ACPU are static tests, where the patient resists the load without the ability to move.

In this study, ACPU and Speed's were high performers with regards to LHBB activation, but from a biomechanical standpoint and from an examination of the actual physical movements involved in the two tests, there are clear differences. These tests vary substantially in that ACPU is intended to be a static test, while Speed's is normally performed dynamically. Furthermore, these tests have slight but noteworthy differences in patient orientation and type of movement. ACPU places the patient's arm in 30° of horizontal adduction while Speed's test is confined to the sagittal plane. These small but clear and potentially important differences may prove to be an avenue for understanding and the role and importance of SLAP lesion test characteristics and design. A close examination of these kinds of test characteristics and their relation to test performance may help identify a means of improving the clinical detection of SLAP lesions by enabling a new direction to be taken in the design of the clinical tests.

The Active Compression test, utilizes two different arm positions. The subject is first tested with the arm flexed 90°, horizontally adducted 30°, and internally rotated so that the thumb points downward (ACPD). Then the arm is fully supinated and the test is repeated (ACPU). If pain is elicited in the first maneuver and alleviated in the second maneuver the test is said to be positive for a SLAP lesion.²³ Assuming LHBB activation and the resulting tension in

the biceps tendon are good predictors of a SLAP lesion, our findings on the ACPU test run contrary to O'Brien's original design. ACPU test had greater peak LHBB activation than the ACPD test, meaning the ACPU test should create a greater tensile load along the biceps tendon and thus greater pain in the case of an actual SLAP lesion.

O'Brien's basis for the Active Compression test was founded upon cadaveric tests which approximated acromioclavicular (AC) joint compression at several joint positions.²³ O'Brien selected the two positions which resulted in the greatest and least load at the AC joint, ACPD and ACPU respectively. O'Brien's methods accounted for the "active compression" that could be placed on the injured labral area by direct contact with the greater tuberosity but did not account for any tensile loads caused by activation of the LHBB during the clinical test. This may be why many of the clinical based studies on the Active Compression test have resulted in relatively low specificity and sensitivity^{11,20,22,29}. This result demonstrates that there are multiple diagnostic mechanisms to take into account when designing either a single clinical test or when attempting to combine multiple clinical tests.

Although the focus of this study was the behavior of the LHBB, six other joint stabilizing muscles were studied to allow for LHBB selectivity calculations, and to facilitate characterizing any other muscle behaviors or patterns. Peak muscle activities and muscle selectivity were examined for all remaining muscles (SHBB, DELT, PECT, LAT, INFRA, and SUPRA), and statistical analysis revealed that it may be unnecessary to monitor the LAT and INFRA during these tests, because none of the tests had a significant difference in terms of activation of the LAT or in selectively isolating either the LAT or INFRA muscles.

The primary limitation of this study is that the subjects had no history of shoulder pathology; therefore labral symptoms were not used as a means to assess SLAP test performance. Also the healthy subject pool may misrepresent SLAP lesion patients due to the potential for differences in muscle behavior between healthy subjects and those with labral pathology. Furthermore, the EMG signals were all normalized based on peak activities elicited during MVIC, and results exceeded 100% in some cases and may make comparison between subjects difficult. Specifically, the dynamic Speed's test, which had the largest mean activation (140.9% MVIC) among the tests, was not a surprising finding, as the dynamic movement was normalized to a static MVIC. Comparing activation during a dynamic test to data collected in a static configuration may not be optimal. For the static tests, LHBB activations were generally below or much less than that of Speed's, suggesting that the normalization procedure was more appropriate for those tests. However, in some tests subjects were able to achieve more than 100% MVIC in some muscles, which means either that the tests were more effective in isolating those muscles than the MVIC configurations, or that slight differences in positioning or in subject effort in the clinical tests and the MVIC tests affected the muscle activation values recorded. Recent studies utilizing arthroscopic verification for clinical tests have documented a drastic increase in SLAP lesion detection by using the indications of two or more SLAP tests, specifically when at least one test is highly sensitive and another is highly specific^{8, 24}. Consequently, assessing the array of 'high performing' test combinations, utilizing various combinations of single measure high performance tests with various test characteristics may have surprising results and prove worthwhile.

Although this study focuses completely on the amount LHBB activation present during each of the clinical tests, there is a second diagnostic mechanism that needs to be addressed. There are many clinical tests available to clinicians that rely on compression of the injury site through translation of the humeral head within the glenoid socket instead of relying on muscle activation. Several examples of these clinical tests are the Compression Rotation, Clunk, Crank, and Anterior Slide tests³¹. While the effectiveness of these tests needs to be

quantified, we are limited by the lack of current technology to accurately quantify motion of the humerus relative to the glenoid *in vivo*. Dynamic three-dimensional imaging would be required to accurately quantify the translation of the humeral head and the resulting impingement upon the injury site.

Lastly, although difficult to determine and requiring a large pool of control and experimental data, comparisons between the muscle behaviors of a healthy population and those who have a suspected SLAP lesion may illuminate some general pattern differences that could be indicative of SLAP lesions and be useful for furthering clinical diagnostic techniques and accuracy.

Conclusions

In summary, modified versions of Bicep I and Bicep II resulted in the greatest LHBB activation and LHBB selectivity of the SLAP lesion tests in this study. ACPU, and Speed's resulted in the large LHBB activation, but were not selective for the LHBB. Bicep I, Bicep II, ACPU, and Speed's each elicit some promising LHBB behavior, and maybe useful in combination to aid the clinical detection of SLAP lesions. These four tests utilize a unique range of test variables that may prove valuable for optimal SLAP test design and function. Future studies should evaluate the importance of these variables, incorporate joint torque analyses, and expand the scope of the study to include patients who have a suspected SLAP lesion to optimize, validate, and improve the diagnostic accuracy of provocative SLAP lesion tests.

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Figure 1.

Top Row – Bicep I, Bicep II, ProLoad; Middle Row – RSER, Speed's, Yergason's; Bottom Row – ACPD, ACPU

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

Figure 3.
LHBB mean muscle selectivity for each SLAP test.

Table I

MVIC joint positions and resisted maneuvers for the seven muscles of interest.

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

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Table III

Resulting mean muscle selectivity values and standard deviations monitored during each SLAP lesion test.

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 n	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)