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On the kinematics of the cross body abduction and hand behind the back tests to assess osteoarthritis of the acromioclavicular joint

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ABSTRACT

Background: Osteoarthritis of the acromioclavicular joint is one of the most common sources of shoulder pain. One of the current standard clinical physical examination tests is the cross body adduction test which has been shown to signal the presence of osteoarthritis. Another test referred to as the hand behind the back test has been described to provide a more accurate diagnosis than the CBA test for some patients. Through this work, both the CBA and the HBB tests were modeled in order to determine if there is merit for the HBB test to be used as a diagnostic tool for clinicians.
Methods: Both tests were modeled using the zygote solid 3D 50th percentile male human anatomy model and MSC-ADAMS Software to compile and run the simulations. Within MSC-ADAMS the bones were outfitted with joints. During simulation, the bones were moved from the anatomical position to the final position for each test and the corresponding minimum distances between the bones at the acromioclavicular joint were then determined.
Results: It was found that the distance between the acromioclavicular joint articulating surfaces decreased by 0.3 mm from the anatomical position during the CBA test and by 1.65 mm from the anatomical position during the HBB. This shows that the minimum space decreased from the anatomical position by more than 5 folds during the HBB test than during the CBA test.
Conclusions: These results indicate that the HBB test may be a better diagnostic test due to the greater stress and irritation it places upon the acromioclavicular joint.

Keywords: Acromioclavicular Joint, Osteoarthritis, MSC-ADAM

INTRODUCTION

Osteoarthritis (OA) of the acromioclavicular (AC) joint has been said to be a common source of shoulder pain, and the most common source in patients over the age of 50, with between 54-57% of elderly patients showing radiographic signs of degenerative arthritis at the joint.[1,2] The pain associated with OA of the AC joint has been observed to not be localized directly upon the AC joint lending a difficult time for physicians to diagnose properly; despite this, the pain occurring with OA of the AC joint has been thought to be caused by irritation of the subacromial bursa after the AC joint becomes inflamed or has protruding osteophytes.[3] Currently, one of the primary clinical diagnostic tests for this pathology is the cross body adduction (CBA) test, involving the patient moving the hand of their arm with the pathological shoulder and placing it on the contralateral shoulder.[3] However, recently another test has been proposed the reverse shoulder internal Rotation test which involves placing the hand behind the back, and is abbreviated HBB for short. In a clinical setting, it was observed that some patients test negative for pain while performing the CBA test and positive while performing the HBB test. These patients were then later found to have OA of the AC joint through imaging or arthroscopic means.

Anatomy of the shoulder

The bones that make up the shoulder complex are the clavicle, scapula, and humerus as well as the thorax, which includes the ribs, sternum, and vertebrae.[4] The clavicle is a long bone that attaches medially to the sternum and laterally to the acromion process of the scapula. The thorax involves the ribs, sternum, and vertebrae as well as all organs housed within. In this model, the left ribs were used to help guide the scapula along the ST joint and the right ribs were used as visual references for the final resting positions of the upper limb. The thoracic vertebrae were used to provide attachment points for certain muscles. The sternum, or breastbone, was used to provide a visual aid for understanding the final resting positions of the upper limbs.

There are four articulations/joints that make up the shoulder complex the sternoclavicular (SC) joint, acromioclavicular (AC) joint, glenohumeral (GH) joint, and the scapulothoracic (ST) joint/pseudo-joint. In this work, the SC joint is assumed fixated in space. The AC joint acts as the articulation between the lateral end of the clavicle and the acromion process of the scapula and is incapsulated by the acromioclavicular ligament (ACL). This AC joint, shown in (Figure 1), and has six degrees of freedom (DOFs) that includes translations along the anterior/posterior (A/P), medial/lateral (M/L), and superior/inferior (S/I) directions and rotations through A/P tipping as well as M/L and internal/external (I/E) rotations.[5,6]

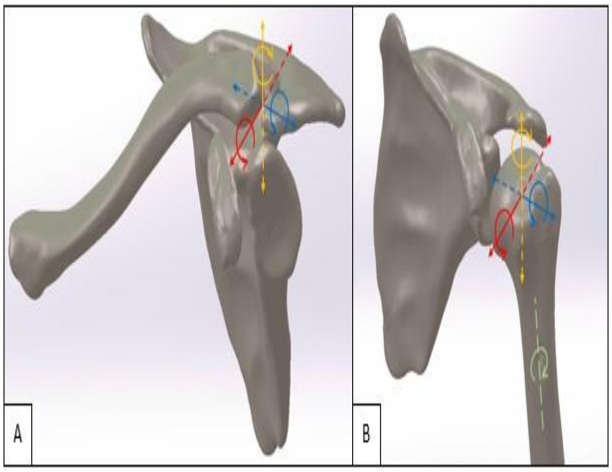

Figure 1: Solid works model highlighting the six degrees of freedom of the- (A) acromioclavicular joint. Red- anterior/posterior translation and medial/lateral rotation of scapula; blue-medial/lateral translation and anterior/posterior tipping of scapula; and yellow-superior/inferior translation and internal/external rotation; and (B) glenohumeral joint. Red-anterior/posterior translation and abduction/adduction rotation; blue-medial/lateral translation and flexion/extension rotation; yellow-superior/inferior translation; and green-internal/external rotation.

The uniqueness of the shape of the AC joint lends additional freedom to the scapula allowing it to follow the curvature of the thorax as the upper limb moves.[6] This movement of the scapula along the thorax is otherwise known as the ST joint. Despite being called a joint it is not a true anatomical joint, but rather it is the closing linkage between the AC and SC joints allowing for the three rotational motions of the scapula pivoting around the AC joint.[6] Lastly, the GH joint is the synovial spheroidal (ball-and-socket) joint that is commonly referred to as the "shoulder joint" and is the articulation between the glenoid fossa of the scapula and the proximal end of the humerus. Having three DOFs, shown in (Figure 1), the GH joint allows for flexion/extension (F/E), abduction/adduction (Ab/Ad), and I/E rotation of the humerus.[6] There are eighteen muscles that correlate to the shoulder complex that have at least one attachment point on either the clavicle, scapula, or humerus. Only four of these muscles allow for the movements studied in this work.[7,8] These muscles which are shown in (Figure 2) are the latissimus dorsi, pectoralis major, subscapularis, and teres major. Within the shoulder there are twelve ligaments; however, four of the ligaments-the coracoclavicular (CCL), glenohumeral (GHL), sternoclavicular (SCL) and acromioclavicular (ACL) ligaments-break down further into multiple segments.[9]

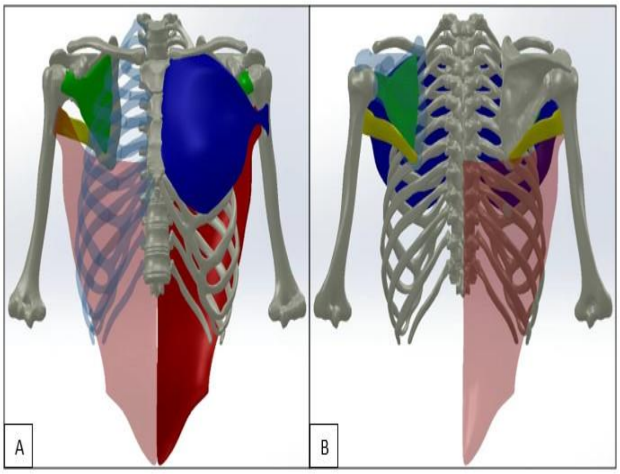

Figure 2: Solid works model of the; a) anterior and b) posterior aspects of the bilateral shoulder, thorax, and relevant muscles-latissimus dorsi (red), pectoralis major (blue), subscapularis (green), and teres major (yellow).

The CCL separates into the conoid ligament (CCL-C) and the trapezoid ligament (CCL-T); the GHL into superior (GHL-S), middle (GHL-M), and inferior (GHL-I) components; the SCL into anterior (SCL-A) and posterior (SCL-P) components, and the ACL into superior (ACL-S) and inferior (ACL-I) components. All seventeen of the structures are listed in (Table 1) with their origin and insertion locations indicated as well as their actions. Seven structures are used in this model which are the ACL-S, ACL-I, CCL-C, CCL-T, GHL-S, GHL-M, and GHL-I, respectively.

Table 1: Seventeen ligamentous structures within the shoulder complex and their origins, insertions, and actions.[9,29]

Ligament name	Abb.	Origin	Insertion	Function
Sternoclavicular; SCL				
Anterior	SCL-A	Anterior superior aspect of manubrium	Superior and anterior aspect of sternal end clavicle	Limits anterior translation of clavicle, Checks anterior movement of clavicular head
Posterior	SCL-P	Posterior superior aspect of manubrium	Superior and posterior aspect of sternal end clavicle	Limits posterior translation of clavicle, Checks posterior movement of clavicular head
Costoclavicular	CCL-2	First rib	Inferior surface of medial clavicle	Limits elevation of pectoral girdle, Checks clavicular elevation and superior glide of clavicle
Interclavicular	ICL	Sternal end of one clavicle	Sternal end of other clavicle	Resists excessive depression/ downward glide of clavicle
Superior Transverse	STL	Base of coracoid process	Medial end of scapular notch	Converts scapular notch into a foreman
Inferior Transverse	ITL	Lateral base of scapular spine	Superior margin of the glenoid cavity	Fixes neurovascular bundles within the spinoglenoid notch
Coracoclavicular; CCL				
Conoid	CCL-C	Base of coracoid process	Inferior aspect of clavicle (inverted cone shape)	Limits scapular depression Limits inferior scapular rotation
Trapezoid	CCL-T	Base of coracoid process (wide)	Inferior aspect of clavicle (quadrilateral shape)	Limits scapular motion during upward clavicle displacement Limits shear forces at the AC joint
Acromioclavicular; ACL				
Superior	ACL-S	Superior lateral end of clavicle	Superior surface of acromion process	Limits posterior translation of ac joint, Limits posterior axial rotation of ac joint
Inferior	ACL-I	Inferior lateral end of clavicle	Inferior surface of acromion process	Limits posterior translation of ac joint, Limits posterior axial rotation of ac joint
Coracoacromial	CAL	Lateral border of coracoid process	Medial border of acromion process	Limits anterior and inferior translation of GH joint during internal and external rotation Stabilizes ac joint and acromion process, Limits superior subluxation of humeral head
Coracoglenoid	CGL	Posterior surface of coracoid process	Superior glenoid tubercle	Undetermined, but speculated to be a stabilizer for superior labrum
Coracohumeral	CHL	Lateral border of coracoid process	Anterior aspect of greater humeral tubercle, Lesser humeral tubercle	Forms a tunnel for the biceps tendon
Glenohumeral; GHL				
Superior	GHL-S	Superior edge of lesser humeral tubercle	Humeral fovea capitis	Limits posterior dislocation and anterior translation of GH joint
Middle	GHL-M	Lesser humeral tubercle	Anterior aspect of proximal humerus, below the GHL-s	Stabilizes GH joint during external rotation, Limits GH joint rotation and translation during abduction
Inferior	GHL-I	Below the articular margin on the inferior humeral head	Anterior inferior glenoid Posterior labrum and capsule	Limits rotation, translation, and abduction of GH joint
Transverse Humeral	THL	Lesser humeral tubercle	Greater humeral tubercle	Keeps the long head of the biceps tendon in groove

Physical examinations for OA of the AC joint

Over the years, OA has become known to occur overtime in a joint when the tissues within break down due to repeated mechanical loading, and it is generally classified as one of two types primary or secondary.[10-13] Primary OA has been said to occur when no obvious cause is present, and secondary OA has been said to have a quicker onset once a traumatic injury, or underlying disease, occurs at the joint.[14,15] For this work, the type of OA that would be present was deemed not to have a significant impact due to both types presenting in a similar fashion. Despite the type of OA not being significant, the loading that occurs at the joint is important-i.e., the closing of the gap between the bones that occurs while OA is present. The CBA test has been shown to close the gap an additional amount in order to irritate the joint and signal the presence of OA, and the HBB test has also been observed clinically to exasperate the pain at the AC joint caused by OA.[3] To demonstrate the closing of the gap, (Figure 3) shows a side-by-side comparison of an AC joint with and without (Figure 3) OA in order to showcase the shortening of the distance between the acromion process of the scapula and the distal end of the clavicle.

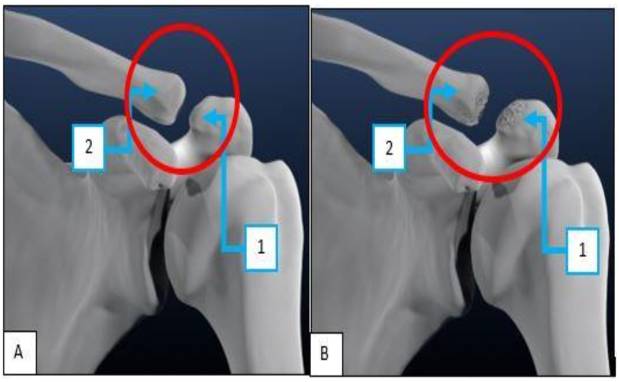

Figure 3: a) an acromioclavicular joint that is pathologically neutral and b) an acromioclavicular joint that is diseased with osteoarthritis, where body 1 is the acromion process of the scapula and body 2 is the clavicle, with the joint spacings highlighted by red ovals.

The most common tests found in literature to diagnose OA of the AC joint are the CBA and HBB tests. The CBA test is performed by having the patient either sit or stand with his arms at his sides, and the patient is asked to flex his shoulder to 90 degrees of forward elevation while the palm is downward facing, shown in (Figure 4) followed by a 90-degree flexion of their elbow. The movement is then finished by the patient adducting his shoulder and elbow until that arm's hand is resting upon his contralateral shoulder, shown in (Figure 4).[16-17] The test can then be pushed further by the physician gently adding force to the patient's elbow furthering the adduction at the shoulder.[16-19] Additionally, this examination can be performed completely passively to the patient by having the physician guide the patient's arm movements until the hand is resting upon his contralateral shoulder. A positive outcome for this test occurs when the patient feels pain at his AC joint. The CBA test can be performed without assistance from a physician.

Figure 4: a) Still showing the beginning the cross body adduction test with 90 degree forward arm flexion and the palm facing downward, b) still showing the continuation the cross body adduction test by adducting the arm across the body towards the contralateral shoulder.

This eliminates the variability that could occur between physicians when applying an unspecified amount of force to the upper limb during testing. The hand behind the back (HBB) test is described as having the patient internally rotate and extend their shoulder while flexing the elbow and reaching towards the thoracic spinal region as shown in (Figure 5).

Figure 5: A still depicting the hand behind the back test.

It is important to note that internal rotation realigns the position of the humeral head placing the greater tubercle in anterior position below the coracoacromial arch. Despite the internal rotation realigning the humeral head into the same orientation, the arm extension ends up maximizing the spacing under the coracoacromial arch by placing the greater tubercle further away from the CAL, thus a positive test would not be likely to elicit the same pain response and create a misdiagnosis between OA and the shoulder impingement test.

Scope of this work

The objective of this work is to examine how the HBB test affects the articulating surfaces of the AC joint-namely the clavicle and acromion process of the scapula. Specifically, this work compared the spacing between the articulating surfaces of the AC joint at the final positioning of both the CBA and HBB tests in order to see if the joint spacing at the HBB test is greater than, less than, or similar to the spacing at the CBA test in order to preliminarily state whether or not the HBB test could be a viable physical examination test for physicians to use in diagnosing OA of the AC joint.

METHODS

Study period and place

This study took place between April 2019 and November 2021 at the University of Toledo (Toledo, OH, USA) college of engineering, biomechanics and assistive technology laboratory of the departments of bioengineering and mechanical, industrial, and manufacturing engineering.

Skeletal model and software utilized

Two software packages and a skeletal model were utilized in this work. The software packages include Solid work by dassault systèmes, which was used to develop the anatomical model and MSC-ADAMS, by MSC Software, which was used to build the kinematic model and to run the simulations.[20-22] The skeletal model used was the Zygote Solid 3D 50th percentile male human anatomy model that came with solid works parts and assembly files of the skeletal system, muscles, connective tissues, and skin; however, this work utilized only the necessary bone files from the skeletal system.[23]

Bones utilized from zygote

The primary bones that were used from the ZYGOTE model were the clavicle and scapula since the AC joint encompasses the articulating surface between these two bones. In addition to these, the humerus was used in order to lead the movement of the scapula as the CBA and HBB motions were performed. Due to the nature of the CBA and HBB movements, the radius and ulna bones of the forearm were combined into a single body, using SolidWorks, as well as the 27 bones of the hand; these bodies were then added into the MSC-ADAMS model in order to ease the visualization process and understand the upper limb's final resting positions for end of both the CBA and HBB tests. Similarly, the thoracic cage was included in the model in order to guide the scapular motion at the ST joint and to verify that the movements were viable on a physiological level. To conceptualize the relative positioning of the segments, as well as to add aesthetics, the lumbar vertebrae (L1-L5) and the pelvis, which includes the pelvic girdle (hip/coxal bone) and the pelvic spine made up of the sacrum and coccyx, were added into the model.[24] Bones were considered as rigid bodies in this work with material properties corresponding to an isotropic cortical bone with a density of 1.79 E-06 kg/mm3.[25]

Joints used in MSC.ADAMS model

The following five joints were modeled using MSC-ADAMS: the sternoclavicular (SC), acromioclavicular (AC), glenohumeral (GH), elbow, and wrist joints. The SC joint, despite being a synovial saddle joint with three degrees of freedom (DOFs), was assumed to be a fixed joint. Accordingly, the clavicle was considered fixed in space, despite truly having minor mobility. The wrist and elbow joints were both modeled as spherical joints with 3 DOFs, despite respectively being a synovial ellipsoid joint and a dual, complex hinge/revolute joint.[5] While the GH joint is a multiaxial spheroidal joint with three rotational DOFs, it was modeled as three, one DOF revolute joints, through adding two spherical bodies centered at the same location as the GH joint, shown in (Figure 6).

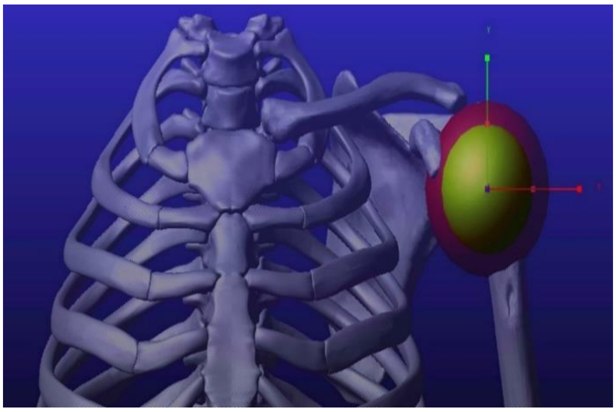

Figure 6: The multibody series within the MSC-ADAMS model that allowed three one degree of freedom revolute joints to chain together to give the glenohumeral joint the same three degrees of freedom that it would receive with a spherical joint. Body one (red) and body two (green).

These spherical bodies were then connected in series between the scapula and humerus-scapula to body one, body one to body two, and body two to humerus-creating a chain of one DOF revolute joints. The scapula to body one revolute joint controlled M/L rotation at the GH joint; body one to body two controlled A/P rotation, and body two to humerus controlled humeral I/E rotation-these were done through changing the alignment of the x-y-z axes of the revolute joints in order to control the direction that its one DOF gave. The AC joint was given six DOFs to observe all movements that would occur between the corresponding articulating surfaces. The clavicle was held to the arcmin process via the surrounding ligamentous structures. The scapulothoracic (ST) joint is not a true anatomical joint; however, it is an articulation between the scapula and the thoracic cage (ribs of the thorax), specifically Ribs 1-7. An articulating spring structure was used in order to simulate the ST joint's articulating movements. Springs normal to the tangents of the connecting ribs were used as shown in (Figure 7). The stiffness and damping of each of these springs were set to 2450 N/mm and 0.72 Ns/mm, respectively.[26,27] The stiffness value of the ST pseudo-joint contact was set to 200 times the stiffness of the muscles following the model created for SIMM/Opensim by Chadwick et al.[26]

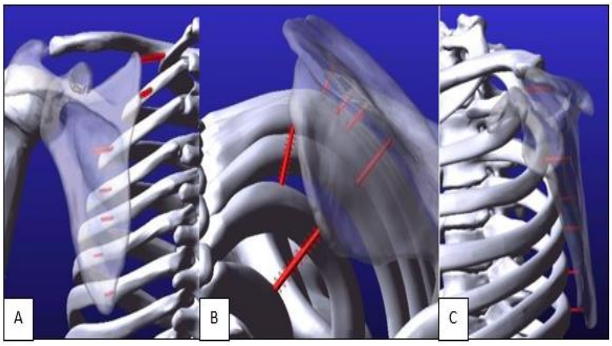

Figure 7: a) Posterior, b) top, and c) lateral views of the ST articulation spring structure. Every spring is normal to the tangent of its connecting riband lies along the transverse plane.

Muscles used in MSC-ADAMS model

Through literature review, the muscles activated during the primary movement of each test were identified-adduction for CBA and internal rotation for HBB. It was found that for CBA the activated muscles were the latissimus dorsi, pectoralis major, and teres major, and for HBB the latissimus dorsi and subscapularis muscles were activated, all shown in (Figure 8).[7,8] All muscles were modeled as applied, single-component forces with a stiffness of 12.25 N/mm and damping of 0.72 Ns/mm mimicking the average arm stiffness and damping values found by Wang et al.[27]

Ligaments Used in MSC-ADAMS model

Due to limitations within MSC.ADAMS that occur when working with rigid bodies, the ligaments that were modeled needed to have their origin and insertion points on separate bones. Also, the costoclavicular and sternoclavicular ligaments were determined to be unnecessary due to their insertion and origin points being on the thorax and the clavicle, of which both bodies were fixated in space.

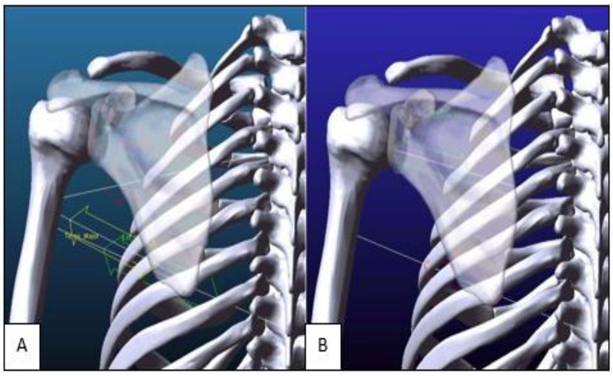

Figure 8: a) The latissimus dorsi (green), pectoralis major (red), and teres major (yellow) muscles used in CBA and b) the latissimus dorsi (green) and subscapularis (red) muscles used in HBB.

Therefore, only the ACL, CCLs, CHL, and GHLs were placed in the model as springs without damping. All of the springs' stiffness coefficient values for the ligaments are expressed in (Table 2) and came from Soslowsky et al.[9]

Table 2: Stiffness values given to each of the ligaments in the MSC-ADAMS model.[9]

Ligament	Stiffness (N/mm)
Acromioclavicular	84
Coracoclavicular	-
Conoid	105
Trapezoid	84
Coracohumeral	36.7
Glenohumeral	17.4

It should be noted, however, that the stiffness for all three sections of the GHL were based upon the value given in literature for the GHL-S due to the stiffnesses of the GHL-M and GHL-I not being stated. Additionally, the ACL stiffness was unable to be located within literature, and therefore was modeled with the stiffness value of the CCL-T due to the similar role that they play in supporting the AC joint as well as the CCL-T being closer in size to the ACL than the CCL-C. Lastly, for this model, the CCL-C was separated into two pieces in order to accurately depict its conical shape.

Calculating distances between articulations of the AC joint

The first measurement taken was the closest distance between the articulating surfaces while the model was in the standard anatomical position. The standard anatomical position is a position that involves the skeleton to be erect with the legs together and the arms held down at the side and the palms facing forward. MSC.ADAMS does not have a function to measure the minimum distance between two bodies, so this was obtained interactively and then compared to the value found in solid works while utilizing the measure tool "measure minimum distance." The interactive value was considered acceptable when it came within 0.02 mm of the SolidWorks measured value-a less than 1% difference. The minimum distance between articulating surfaces of the AC joint were then interactively located and evaluated post simulation. After the model was ran for both the CBA and HBB tests, the minimum distance at the final resting position for each was interactively obtained and spatial markers were placed at those locations on the bodies of each test. Once these markers were placed, a point-to-point measurement was created within the MSC-ADAMS models between those located points-an additional point-to-point measurement was also placed between the located minimum points of the standard anatomical position. Once the tests were ran with the point-to-point measurements in place, both of the measured distances were observed within the MSC-ADAMS Post Processor, and the final minimum distances were recorded respectively from their individual point-to-point measurement recordings. These values were compared to determine the change that occurred between the articulating surfaces at the AC joint while a patient performed each test, and then compared to each other in order to determine if the HBB test has merit as a physical exam for OA of the AC joint. It should be noted that the minimum distances did not occur between the same points on the clavicle and acromion process for any of the three measured positions (initial anatomical position, and final positions for the CBA and HBB tests). This is due to the fact that the surface topography of neither the lateral end of the clavicle nor the acromion process of the scapula are perfectly smooth and spherical-rather there are bumps, ridges, and other surface abnormalities that affect which points will be the closes to each other in any given orientation.[27] he differences between the standard anatomical position's minimum distance and both the CBA and HBB tests interactively found minimum distance points on both the clavicle and acromion process.

RESULTS

Through combining the minimally quantified description of the CBA test as well as personal communications, it was determined by trial and error that the CBA test movements would be completed through seven distinct joint rotations and the HBB test would complete its movements through six distinct joint rotations. These rotations, and their order are listed in (Table 3), which details the type of rotation, which joint it occurred at, and the degree of movement that occurred. Beginning from the standard anatomical position, the CBA test's first movement was a 90-degree internal humeral rotation at the GH joint, which placed the thumb in a forward position and left the upper limb in a 10-degree extension (Table 3). Due to the 10-degree extension, the humerus was rotated 100 degrees of flexion at the GH joint, effectively placing the arm at a 90-degree forward flexion. The third step did not affect the AC joint positioning but did allow the model to stay true to the CBA test's description; therefore, the wrist was placed under 65 degrees of pronation placing the model's palm downward. The GH joint was then adducted 24 degrees towards the contralateral shoulder.

The elbow was then placed under 90 degrees of flexion, moving the hand toward the contralateral shoulder. Lastly, the hand was placed upon the contralateral shoulder utilizing an 18-degree rotation superiorly at the elbow and a 15-degree radial deviation at the wrist. Similarly, the HBB test began from the standard anatomical positioning and had a 90-degree internal humeral rotation at the GH joint, followed by an extension of 45 degrees, then an adduction of 20 degrees placing the forearm behind the back. The elbow then was pronated by 40 degrees followed by a 90-degree pronation at the wrist. Lastly, the elbow was flexed to 120 degrees in order to align the wrist with the fourth thoracic vertebrae.

Minimum distances between articulations

The final resting positions of both CBA and HBB tests are depicted in (Figure 10). These final positions were reached using the data listed in (Table 3). At these final locations the minimum distance between the distal clavicle and acromion process of the scapula were interactively measured. It is reported in the literature that this minimum distance is 3.31 mm. at the standard anatomical position. This distance at the anatomical position was found to be 3.16 and 3.14 mm. when calculated in ADAMS and Solid Works, respectively. At the final resting position, this distance was calculated as 2.86 mm for the CBA test and 1.51 mm for the HBB test.

Table 3: Angles and rotations utilized for both the CBA and HBB tests, in sequential order.

Step	CBA			HBB		
	Angle	Joint	Rotation	Angle	Joint	Rotation
1	90°	GH	Internal humeral	90°	GH	Internal humeral
2	100°	GH	Flexion	45°	GH	Extension
3	65°	Wrist	Pronation	20°	GH	Adduction
4	24°	GH	Adduction	40°	Elbow	Pronation
5	90°	Elbow	Flexion	90°	Wrist	Pronation
6	18°	Elbow	Superior	120°	Elbow	Flexion
7	15°	Wrist	Radial deviation	-	-	-

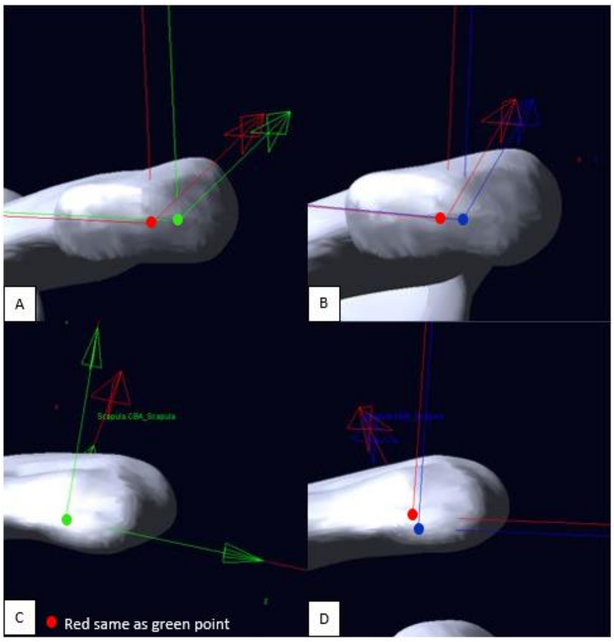

Figure 9: The varying positions of the minimum distance points of both CBA (green) and HBB (blue) resting positions relative to the standard anatomical position (red). Top row depicts the lateral end of the clavicle; bottom row depicts the acromion process of the scapula's medial edge.

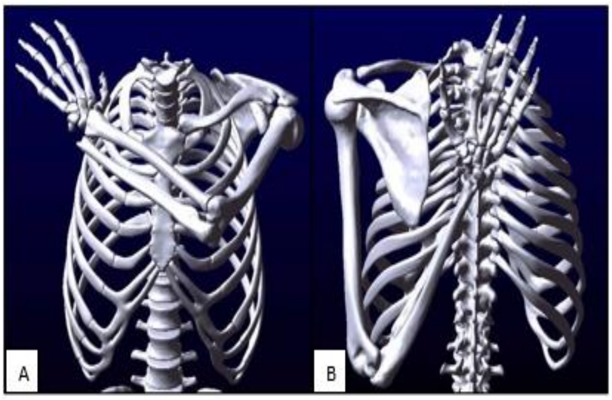

Figure 10: Final resting positions of the a) cross body adduction (anterior view) and b) hand behind the back (posterior view) tests.

DISCUSSION

Osteoarthritis of the acromioclavicular joint is one of the most common sources of shoulder pain due to its ability to break down tissues within a joint due to repeated mechanical loadings. These loading repetitions eventually begin to form osteophytes at the articulating surfaces of the joint effectively increasing the stress at the joint and decreasing the spacing. Due to this decrease of space, the clinical physical examinations done involve moving the arm into positions that decrease the space further causing acute pain at the joint. Mostly, two tests have been used to diagnose OA of the AC joint-these are the CBA and HBB tests. This is the first study to compare both the CBA and HBB tests in order to determine if there is merit for one over the other to be used as a diagnostic tool for clinicians. It is intended to act as the foundation for real world studies to determine the viability of the hand behind the back test.

The zygote solid 3D 50th percentile male human anatomy model was used to model the bones. The MSC-ADAMS software was used to run the simulations to determine the bony final positions when each of these two tests is conducted. Within MSC.ADAMS the bones were outfitted with joints, single-component forces for muscles, and springs for ligaments, and normal to the rib's tangent springs to simulate the scapulothoracic articulation. The SC joint was considered as a fixed joint, which then fixated the clavicle in space. The GH joint was modelled as three, one DOF, revolute (hinge) joints The AC joint was modeled with full rotational and translational freedom, six DOFs. This allowed for observations of how the scapula moved in relation to the clavicle to go unimpeded throughout both tests.

Spherical joints were chosen to model the wrist and elbow where the forearm and hand were combined as a single body. This still allowed for flexion/extension (F/E) as well as pronation/supination (P/S) of the forearm to occur.[24] Several and different joint rotations were specified in order to move from the anatomical position to the final position to simulate the CBA and HBB tests. These rotation angles were determined iteratively by trial and error and by not allowing unrealistic bone positions.

CONCLUSION

It was found that the distance between the acromioclavicular joint articulating surfaces decreased by 0.3 mm from the anatomical position during the cross body adduction test and by 1.65 mm from the anatomical position during the Hand Behind the Back. This shows that the minimum space decreased from the anatomical position by more than 5 folds during the HBB test than during the CBA test. These results indicate that the hand behind the back test may be a better diagnostic test for early-stage osteoarthritis of the acromioclavicular joint due to the greater stress and irritation it places upon the joint. In order to validate these findings, further studies experimental and modeling studies are required. Experimental studies would include X-rays that validate the final positions in each of the two tests. Modeling studies would include performing a detailed finite element analysis to quantify the stresses at the articulating surfaces.

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