Torque Capabilities of the Trapezius

Brandon Busch SPT
Craig Dorn SPT
Alisha Fey SPT
Lindsey Laux SPT

Advisor: Paula Ludewig PhD
PhD Student: Dan Hassett PT

2004 – 2006

Table of Contents

Introduction

The shoulder complex, commonly described as one of the most complicated regions of the human body, is made up of three segments (the humerus, the clavicle, and the scapula) that all move relative to the thorax. [8] It is made up of three synovial joints (the sternoclavicular, acromioclavicular, and the glenohumeral joints), and the scapulothoracic articulation. [8] The actions that occur at these joints as a result of elevation or depression of the arm occur simultaneously, not successively. [3] Therefore, each joint in the shoulder complex is dependent upon the actions of the others. In this fashion, movement of the upper extremity at the glenohumeral joint occurs along with movement of the scapula. Scapular kinematics, which are three-dimensional in nature, are controlled by the actions of the scapular muscles and their abilities to create torque. Therefore, neither scapular kinematics nor the torques acting on the scapula can be adequately represented with two-dimensional analysis. In order to fully capture the nature of these relationships, analysis during normal dynamic movement is also needed in addition to the current body of knowledge generated from the study of static scapular positions and muscle actions. This paper will discuss scapular kinematics and the role of the trapezius and serratus anterior muscles in controlling these movements with respect to three dimensions.

Dr. Verne Inman was the first person to attempt to "derive a comprehensive picture of the whole" when studying the actions of the shoulder complex. [3] In the January 1944 edition of *The Journal of Bone and Joint Surgery* in an article entitled "Observations on the Function of the Shoulder Joint", Inman coined the original description of the scapulohumeral rhythm. He stated that between 30 and 170˚ of elevation of the arm (after the first 30˚ of abduction in the coronal plane or 60˚ of forward flexion), a 2-to-1 ratio of humeral elevation to scapular upward rotation occurs. [3] Inman also said that prior to 30˚ of elevation, the scapula is undergoing a "setting phase" in which it is seeking a stable position in relation to the position of the humerus. This "setting phase" is very irregular, is dependent upon the resting position of the scapula, and is generally characteristic of the individual. [3]

Two-dimensional methods of studying scapular motions, such as those employed by Inman, are not able to account for "out of plane" motions of the scapula and do not display the true complexity of the movement. [6] Therefore, three-dimensional research has built upon Inman's original two-dimensional description of the scapulohumeral rhythm (upward/downward rotation of the scapula about an axis perpendicular to the plane of the scapula) by including rotation about an approximately medial/lateral axis (anterior/posterior tipping) and rotation about an approximately vertical axis (internal/external rotation) during elevation of the arm. [4-7] Translational motions of the scapula also occur during elevation of the arm. These translations are defined by rotation of the clavicle about the sternoclavicular joint. Inferior/superior translations of the scapula upon the thorax occur with clavicular elevation / depression. Medial/lateral translations of the scapula upon the thorax occur with clavicular protraction / retraction. [4] Scapular upward rotation, posterior tilting, and external rotation occur during elevation of the arm [4-7], along with clavicular elevation, retraction, and posterior rotation. [3, 6]

According to McClure et al., upward rotation of the scapula is generally assumed to have a nonlinear relationship with humeral elevation. [6] Although the middle ranges of the motion appear to have a fairly linear relationship, during the first 30˚ of elevation of the arm the scapula does not move much, which would seem to be in agreement with Inman's statement concerning the "setting phase". The nonlinear relationship also exists because at the extremes of elevation the rate of scapular upward rotation increases when compared to the middle ranges of elevation. [6] In a three-dimensional bone pine study, McClure and colleagues defined the average value of scapular upward rotation to be 50˚ during scapular plane elevation and 46˚ during glenohumeral flexion.[4] Upward rotation of the scapula also occurs during external rotation of the humerus at the end range of the motion with little scapular motion occurring during the beginning of the motion.[6]

Upward rotation of the scapula during elevation of the arm is important because it elevates the lateral acromion, preventing impingement of the structures that pass underneath it.[5] Studies have shown that a decreased amount of scapular upward rotation during humeral elevation has been linked to symptoms of subacromial shoulder impingement.[4,5,7] One theory as to why this happens is that decreased upward rotation brings the greater tuberosity of the humerus closer to the coracoacromial arch during elevation of the arm, leading to compression of the rotator cuff structures.[5]

During elevation of the arm, the scapula tips from an anterior to a more posterior position about a medial/lateral axis.[7] The pattern of posterior tipping to glenohumeral elevation is nonlinear, as the tipping occurs mostly above 90˚ of elevation with a large increase at the end range of the motion.[6] Although the amount of posterior tilting that occurs varies greatly among the available literature,[6] a study by McClure and colleagues in 2001 found that an average of 30˚ of posterior tilting occurred during scapular plane elevation of the arm and an average of 31˚ of posterior tilting occurred during glenohumeral flexion.[4] Posterior tilting of the scapula also occurs at the end range of motion during external rotation of the humerus.[6]

Posterior tilting of the scapula is important during elevation of the arm because it elevates the anterior acromion to allow clearance of the head of the humerus and the rotator cuff tendons that pass under the acromion.[5, 6] This is important because the anterior acromion is the most predominant site for impingement to occur.[5] Studies have shown that subjects who experience symptoms of impingement of tissues in the subacromial space exhibit decreased posterior tipping, or they move towards a more anteriorly tipped position of the scapula during elevation of the arm. [4-7, 10] Anterior tilting of the scapula is also a component of increased abnormal scapular winging that occurs with glenohumeral elevation. [4]

As previously stated, external rotation of the scapula also occurs with elevation of the arm. During external rotation, the lateral border of the scapula moves posteriorly. [4] The pattern of external rotation with arm elevation is nonlinear, and the majority of the external rotation of the scapula occurs past 90˚ of elevation of the arm with a great increase in the amount of rotation at the end of the range of motion. [6] It is speculated that external rotation of the scapula may decrease the need for glenohumeral external rotation with elevation of the arm, which will in turn decrease the chances for capsular laxity and anterior instability at the glenohumeral joint. [6] External rotation of the scapula also occurs at the end range of motion during external rotation of the humerus. [6] A three-dimensional study by McClure and colleagues found average values for external rotation of the scapula to be 24˚ during scapular plane elevation of the arm and 26˚ during glenohumeral flexion. [4] Increased scapular medial rotation (or decreased external rotation of the scapula) has been shown in subjects with impingement. [5] Medial rotation of the scapula also contributes to abnormal scapular winging during glenohumeral elevation. [4]

The muscles of the shoulder complex greatly influence scapulohumeral rhythm. The trapezius and the serratus anterior are two primary movers of the shoulder that we will address. Anatomical studies show that the trapezius is divided into three distinct parts: the upper, middle, and lower trapezius[1]. The trapezius extends from the occiput into the lower thoracic region, and extends laterally as far as the acromion. [2] The actual origins and insertions of these parts, as well as their actions, vary greatly among literature. Johnson et al[2] performed a study on the three parts of the trapezius by dissecting cadavers and followed each fascicle of the trapezius to its distinct attachment site. They found the superior (nuchal) part to arise from the superior nuchal line and the ligamentum nuchae. This part inserts into the lateral third of the clavicle. The fascicles from C_7 and T_1 make up the middle part of the trapezius. The C_7 fascicle goes to the acromion and the T_1 fascicle goes to the spine of the scapula. The lower part is made up of the fascicles from the spinous processes below T_1 and they insert on the deltoid tubercle of the scapula. [2]

Johnson et al[2] also looked at the pattern and direction of the different fibers of the trapezius. They found the fibers from the superior nuchal line are the only fibers to have any major degree of downward orientation and that the other fibers of the nuchal portion run transversely to the clavicle. From this orientation, the nuchal portion of the trapezius is not likely to act as a scapular elevator. Also, these fibers act on the clavicle not the scapula, therefore, their transverse orientation acts to draw the clavicle backwards and medially, but not upwards. [2] The C_7 and T_1 fibers are located very close to the axis of rotation of the scapula, and therefore, their relative short moment arms compromise their ability to produce an upward rotary moment. The thoracic fibers of the trapezius do not substantially change length throughout the range of upward rotation of the scapula. Therefore, they maintain the horizontal and vertical equilibrium of the scapula rather than generating net torque. [2] This shows that the fibers direction and orientation affect the action of the different parts of the trapezius.

The serratus anterior is an important scapulothoracic muscle in allowing for the realization of the full potential of shoulder joint motion. It originates at the anterolateral aspect of the upper eight or nine ribs and attaches to the anterior surface of the vertebral border of the scapula from the superior angle all the way to the inferior angle. The serratus anterior is often divided into two function parts: the superior (upper) and inferior (lower) portions, lower component consisting of the inferior four digitations of the muscle. Therefore, Inman et al[3] state, "the action of a single muscle, such as serratus, differs in its individual parts." Consequently, this one muscle, similar to the trapezius, can simultaneously have different effects on the scapula. The main functions of the serratus anterior muscle are to keep the scapula against the thoracic wall as well as protraction and upward rotation of the scapula. Ludewig and Cook[5] also point out that, "The serratus anterior muscle is believed to provide the primary muscular force to produce posterior tipping of the scapula and stabilize the scapular inferior angle against the thorax during humeral elevation." This muscle is critical in producing horizontal movements such as pushing or "plus" movements (excessive protraction of the scapula). However, the serratus anterior is most effective and most useful as part of a force couple with the trapezius.

The serratus anterior must work along with other muscles, namely the trapezius, in order to provide normal scapulohumeral rhythm, which is necessary for proper arm movement. In fact, Ludewig and Cook[5] suggest that normal scapular rhythm and upward rotation are linked to a balance in force production between the serratus anterior and trapezius muscles. Halder, Itoi, and An[9] assert, in their discussion of the anatomy and biomechanics of the shoulder, that, "The upper trapezius, upper digitations of the serratus anterior, and levator scapulae form the upper part of the force couple. The lower trapezius and lower digitations of the serratus anterior form the lower part of the force couple." Inman[3] stated that the upper unit of the force couple provides passive support of the shoulder, actively elevates the shoulder, and is the upper component of the force couple that is necessary for scapular rotation. This group shows evidence of an action current potential when the arm is at rest, which demonstrates a postural function of the group. [1] The middle trapezius was found to be most active in abduction as it serves to fix the scapula in its plane of motion during this movement. It also was shown to relax during forward arm flexion thus allowing the scapula to rotate on the thorax. [1]

Michener[4] points out that, "During glenohumeral elevation, the serratus anterior is required to work in concert with the trapezius to upwardly rotate the scapula to allow free movement of subacromial structures under the coracoacromial arch." For example, when looking at glenohumeral elevation[4] and abduction in the scapular plane[1], researchers have found that during the initial phase of elevation the upper trapezius and the lower serratus anterior are the most active and are the main components of the necessary force couple. The model created by Bagg and Forrest[1] showed that the upper trapezius and lower serratus anterior have relatively large force arms and electrical activity in comparison to those of the middle and lower trapezius during phase one. However, during the middle phase, the lower serratus anterior activity plateaus while the lower trapezius activity increases. During the final phase, the scapular contribution to elevation decreases and is achieved through more glenohumeral motion. Consequently, the lower serratus anterior and the lower trapezius are essentially equal in activity during this final phase. The lower serratus anterior must resist the retraction forces of the trapezius muscle in order to allow for glenohumeral motion. Therefore, this information helps to clarify the rotary force couple that is present between the upper trapezius and the lower serratus anterior that is necessary to produce upward scapular rotation during the first phase of arm abduction. This relationship is also expressed in the scapular protraction function of the serratus anterior. Johnson[2] asserts that the lower trapezius resists this motion of the scapula laterally around the chest wall.

The trapezius-serratus anterior force couple is not only important for its role in the upward rotation of the scapula, but it is also a key component in the stabilization of the scapula, which allows for efficient deltoid action of the glenohumeral joint. [10] Levangie and Norkin[10] point out that, “The trapezius and serratus anterior maintain optimal length-tension in the deltoid.” This allows for the deltoid to elevate the arm rather than downwardly rotate the scapula, which would prevent humeral elevation. “The trapezius and serratus anterior produce desired scapular upward rotation, while preventing undesired movement by the deltoid as it elevates the [glenohumeral] joint.” [10] Significant deviations from this normal force couple between the serratus anterior and the trapezius can lead to abnormal scapulohumeral rhythm, which can lead to limits in range of motion or a number of other pathologies.

Ludewig and Cook[5] have suggested that, “Abnormal scapulohumeral rhythm or decreases in upward rotation of the scapula during humeral elevation have been linked to “imbalances” in force production of the upper and lower portions of the trapezius muscle and the serratus anterior muscle.” Therefore, deficits in the serratus anterior and trapezius muscles may adversely affect scapular motion, which Ludewig and Cook[5] assert contributes to shoulder impingement problems. They looked at the shoulders of construction workers with and increased risk of shoulder impingement and compared them to control subjects. They found that subjects with shoulder impingement syndrome tend to have an increase in muscle activity of the upper trapezius in the final two phases of arm elevation as well as an increase in the lower trapezius muscle activity, which is greater than that of the upper trapezius[5]. This study also reported a decrease in activation of the lower serratus anterior[5]. Additionally, Ludewig and Cook[5] concluded that there was an increase in anterior tilting and internal rotation during glenohumeral elevation in subjects with impingement. Similarly, Wadsworth and Bullock-Saxton[14], state that, “Swimmers with impingement syndrome have demonstrated an increased variability in the onset of recruitment of the lower and upper trapezius and serratus anterior during glenohumeral elevation." Furthermore, research, performed by McQuade et al, found that in the range of 60-150˚ of glenohumeral elevation, fatigue of the serratus anterior may negatively affect the scapulohumeral rhythm[15].

Paralysis of the serratus anterior will cause problems such as a condition called winging scapula. The greatest effect of a loss of the serratus anterior can be seen in shoulder flexion. Levangie and Norkin[10] suggest that with a functional trapezius muscle but in the absence of serratus anterior activity, shoulder flexion is limited to a range of only 130˚ or 140˚ (Halder[9] states 90˚ of flexion) along with decreased strength. They state, "When the scapular retraction component of the trapezius is unopposed by the serratus anterior, the trapezius is unable to upwardly rotate the scapula more than 20˚ of its potential 60˚." Levangie and Norkin[10] also state that if the serratus anterior is functional and the action of the trapezius is absent, abduction of the arm will be both weakened and limited in range to 75°. They state, "Without the trapezius (with or without the serratus anterior), the scapula rests in a downwardly rotated position due to the unopposed effect of gravity on the scapula."

When discussing scapulothoracic rhythm and the corresponding scapulothoracic musculature, it is immediately apparent that accurate measurement of the structures involved is extremely difficult. The complexities of the serratus anterior and the trapezius are evident by their broad origins and insertions and make finding their line of action very difficult. Additionally, the complex three-dimensional movements of the scapula and its reliance on the acromioclavicular and sternoclavicular joints have impeded the search for an accurate instantaneous center of rotation. Although much work has been done recently to try to quantify scapular movement, the error of non-invasive techniques, and a lack of real-life three-dimensional kinematic data has made quantifying the movements and torques involved an ongoing task.

Scapular kinematics cannot be described with the same terminology that is used when describing other joints in the body such as simply flexion, extension or rotation. Due to the unique motions inherent to this joint, scapular movement on the thorax must be described with regards to the scapular plane. Upward/downward, medial/lateral rotations, retraction, protraction, elevation, depression, and anterior/posterior tipping are all used to describe scapular movements in regards to single plane rotations or translations. However, the kinematics of the scapulothoracic articulation are really a combination of several of these motions in three different planes occurring simultaneously during humeral abduction, flexion, or rotation. Therefore, there is a need for measurement of the scapula with respect to three dimensions.

Measuring scapular kinematics three-dimensionally has been accomplished through two general techniques. A non-invasive method of placing sensors on the scapula and thorax with tape is commonly used, but apparent errors in measurements due to skin slip between the scapula and the sensor brought out the need for validation of the technique.[11] Another method relies on an in vivo process that uses bone pins inserted directly into the scapula to measure scapular kinematics. In this way there is no error due to skin movement to sway the position of the sensors. One such bone pin study sought to evaluate the validity of two non-invasive techniques, and found that these techniques were "well suited for capturing the essence of the motion patterns."[11] Still, due to errors in measurement with non-invasive techniques, bone pin studies must be done to evaluate the accuracy of less invasive skin based techniques.

Movement of the scapula is dependent on the two joints that make up its connection to the thorax and the corresponding articulation with the rib cage. Due to these dependencies, the instantaneous center of rotation (ICR) of the scapula is constantly changing during elevation of the arm. Several authors have investigated this phenomenon and found the sternoclavicular joint to have the most movement during the initial phase of elevation and the acromioclavicular joint to be the main contributor to the last phase of arm elevation.[1] Bagg and Forrest[1] describe the motion of the ICR as moving from the root of the spine of the scapula to the acromioclavicular joint as the arm elevates. This study used a static 2-dimensional approach to investigate the ICR. Based on a literature search, there are no studies that describe this change in ICR in a three-dimensional fashion. Assuming posterior tipping as well as external rotation of the scapula during scapular abduction of the arm, [6] the axis for the ICR would most likely pivot in an inferior and medial direction with scapular elevation as well as the known shift from the root of the spine of the scapula to the acromioclavicular joint.

Due to the nature of the muscles involved with scapular rotation, determining lines of action for these muscles is difficult. Unlike muscles with central tendons such as the biceps brachii or quadriceps, the upper, middle, and lower trapezius attach on the scapula in a broad fashion with each fiber creating torque at a unique angle. Therefore describing the trapezius in the traditional sense as simply an upward rotator is incomplete and inaccurate. Although the trapezius shows activation with upward rotation, [3] the orientation of its fibers suggests a horizontal or retracting force on the scapula, and it therefore provides more of a stabilizing force than a rotational torque. [2] The thoracic fibers of the trapezius do not vary in length a great deal during humeral elevation, therefore reinforcing their role as primarily a stabilizer. [2] Again, due to the nature of its fiber alignment in relation to the scapular ICR (fibers having essentially no moment arm and acting almost directly on the axis of rotation), the trapezius is only able to act as an effective scapular rotator with help from forces produced by serratus anterior. [2] With its upper fibers producing force in a completely different direction from the middle and lower fibers, the trapezius is uniquely designed to adapt to the constantly changing scapular axis of rotation.

Electromyographic (EMG) data has traditionally been used to infer muscle action based on the amount of muscle electrical activity.[3] However, due to the complex nature of the trapezius and the serratus anterior, EMG data received during scapular stabilization may be misinterpreted as concentric action. EMG activity simply serves as an indicator of muscle activity and does not designate that the muscle is a prime mover. In the case of complex muscles such as the trapezius and serratus anterior, EMG data must be combined with kinematic data in order to come to accurate conclusions about the muscles.

Other justifications for studying the three-dimensional torque capabilities of scapulothoracic muscles (trapezius and serratus anterior) stem from the gaps in the collective knowledge regarding the between subject variation and the difficulty in conducting measurements. Better understanding of scapulothoracic kinematics and the torque producing capabilities of the trapezius and serratus anterior are important to the body of knowledge that could help to develop treatment programs to alleviate shoulder pathologies.

Because subacromial impingement syndrome (SAIS) is the most common disorder of the shoulder (comprising 44% to 65% of complaints of shoulder pain by patients during visits to the doctor's office, according to Vecchio et al. [13)], it is of great interest to physical therapists. SAIS can lead to tearing of rotator cuff tendons and degenerative joint disease of the joints of the shoulder complex, leading to functional loss and even disability of the patient. [4] There are many forms of SAIS, which can make treatment difficult. [4] It is believed that abnormal scapulothoracic kinematics may lead to the development or progression of impingement. [7] Many researchers believe that by gaining better knowledge concerning the normal scapular motions and factors that control it we will be able to build a better base for understanding pathologies related to abnormal scapular control.[6] Because shoulder pathologies such as subacromial impingement syndrome have such a detrimental effect on patients, it is important that we are able to learn all that we can with regards to normal and abnormal scapulothoracic kinematics. This knowledge will help to develop better and more effective treatment options for our patients.

In conclusion, normal scapular motion is controlled by the scapulothoracic muscles with a large contribution from the trapezius and serratus anterior. This motion occurs in three planes, which therefore presents a need for further three-dimensional analysis of scapulothoracic muscle function in addition to the current body of two-dimensional research. By contributing to the body of knowledge of normal scapular motion in three dimensions, a better biomechanical model can be built in order to develop more effective treatment options for pathologies that result from deviations from normal motion. Therefore, the purpose of our study is to quantify three-dimensional torque capabilities of the trapezius and serratus anterior muscles on the scapula.

Subjects

Up to twelve healthy subjects with no history of shoulder pain or pathology were tested during this experiment. These subjects were recruited through the academic and medical professional communities at the University of Minnesota and other medical clinics in the Minneapolis/St. Paul Metropolitan area. In order to be considered eligible for this study, the subjects had to meet the following criteria:

1. must be between 18 and 60 years of age.
2. must have full, pain free shoulder range of motion in all directions.
3. no history of pain, fracture, weakness, or trauma of the shoulder (including dislocation of the sternoclavicular, acromioclavicular, or glenohumeral joints).
4. no history of scoliosis, because scoliosis may cause abnormal scapular positioning upon the thorax.

5. during clinical screening examination, no shoulder pain or upper extremity radiating symptoms can occur.

Because members of both genders and all races may experience shoulder pain, it was attempted to make the subject pool representative of the demographics of the local population with open enrollment for all races and genders.

Individuals who were interested in becoming subjects were first screened over the telephone to identify whether or not they were appropriate for the study. The primary investigator, a licensed physical therapist, reviewed relevant prior medical history and performed a clinical examination to ensure that all subjects met the inclusion criteria of the study. The investigator also gathered information regarding any activities that the individual participated in involving frequent or repetitive shoulder motions.

All subjects involved in the study completed informed consent procedures. They were all notified of the purposes, risks, and benefits of the study.

Hypotheses

Trapezius

1. Due to its angle of insertion on the clavicle, the torque capability of the upper trapezius to elevate the clavicle will decrease as scapular plane abduction increases, therefore decreasing its ability to upwardly rotate the scapula.

2. As scapular plane abduction increases, the torque capability of the lower trapezius to posteriorly tip the scapula will decrease.

3. The lower trapezius contributes more to posterior tipping of the scapula than middle trapezius due to its angle of insertion and greater ability to produce torque during scapular plane abduction.

4. Because of the insertion of the upper trapezius on the posterior and superior aspect of the distal clavicle, the upper trapezius will have a greater ability to produce elevation, verses protraction and posterior long-axis rotation of the clavicle.

Serratus Anterior

5. As scapular plane abduction increases, the lower fibers of the serratus anterior will have their greatest potential to produce torque contributing to upward rotation of the scapula. This torque capability will also decrease as elevation increases.

Procedures

Subjects meeting the inclusion criteria were asked to read, understand and sign a consent form before participating in the study. Three stainless steel pins with a diameter of 2.5 mm were inserted directly into the lateral spine of the scapula, the mid-portion of the clavicle and at the deltoid insertion of the humerus. The pins were placed by Dr. LaPrade, an experienced orthopedic surgeon who has performed many hardware placements for fracture fixations. Dr. LaPrade also performed similar procedures with the same bone pin placement on cadavers. In order to prevent infection, pin insertion were preceded by cleaning the skin with a Providone/Iodine solution and performed with sterile procedures. The subject were then given a local anesthetic into the skin where a 1.25cm cut was made for the pin insertion as well as in the periostium where the pins were placed. In order to ensure safety and proper placement of the pin, C-arm fluoroscopy was used. Once pins have been inserted, registration blocks were attached to them in order to secure sensors immediately adjacent to the pins. Both blocks and pins have been shown in previous studies to not interfere with the sensor tracking. Surface sensors were also placed with self-adhesive tape on areas shown to have the least amount of tissue bulk and skin slip. These areas include the scapular acromion, central third of the clavicle, manubrium, and on a thermoplastic cuff attached to the distal humerus.

After the bone pins and surface sensors were in place, anatomical landmarks were palpated and digitized in order to define the planes of rotation and allow the set up of anatomical coordinate systems. Digitized landmarks include the following: C7, T8, xyphoid process, sternal notch, sternoclavicular joint, acromioclavicular joint, lateral scapular acromion, inferior angle of scapula, root of spine of scapula, lateral and medial epicondyles and a jig placed on the clavicle (3rd point needed to define the vertical plane). In order to estimate the center of the humeral head, the humerus was rotated to 18 positions in multiple planes of 45 degree rotations or less. Therefore data from the sensors can then be adapted to match clinically defined motions such as adduction/abduction, flexion/extension, and internal/external rotation. After digitization is finished, subjects were then asked to perform 2-3 reps, on a 2 second per elevation cycle, of shoulder scapular plane abduction, coronal plane abduction, flexion, internal and external rotation, and free overhead reaching. The subjects were asked to perform a full range of motion (as much as possible considering some limitations in range due to the pins) and were given a stationary screen in which to run their arm against in order to keep a constant angle. Licensed physical therapists then performed a series of clinical tests on the subject. After data was collected, Dr. LaPrade removed the pins, again using sterile procedures. Incisions were then cleaned and closed using a self-adhesive bandage. Subject's pain level was recorded every 30 minutes using a Numeric Rating Scale.

Instrumentation

The Flock of Birds® (miniBird®) hardware (Ascension Technology Corporation, Burlington, VT) was used in conjunction with MotionMonitor™ software (Innovative Sports Training, Inc. Chicago, IL) for obtaining and processing kinematic data. The Flock of Birds® is a direct current electromagnetic tracking device. Multiple small, lightweight sensors (1.8 x 0.8 x 0.8 cm) that are located relative to a source transmitter were used. An electromagnetic field is produced by the transmitter which induces current into the sensors. The sensors then send information about position and orientation to the computer via an electronics unit. The hardware induces a stylus which is able to accurately digitize anatomical landmarks and allows the simultaneous tracking of up to 7 body segments with 7 sensors. The device can track the X, Y, and Z positional coordinates and orientation angles of each sensor with six degrees of freedom at sampling rates of 30-144 Hz. The sampling rate in this investigation was 100 measurements per second. The positional accuracy of the device is 0.18 cm RMS and 0.5° RMS for orientation measurements within 76 cm of the transmitter in a metal free environment.

MotionMonitor™ software allows for establishing local coordinate systems for each segment of interest. Data from the kinematic sensors can be expressed relative to any other tracked segment or sensor. Linear and angular position, orientation, and velocity for multiple segments can be exported for subsequent statistical analysis.

The shoulder model used for analysis was developed using the Software for Interactive Musculoskeletal Modeling (SIMM, Musculographics Inc., IL, USA), which allows the user to make changes in the muscle and skeletal components of the model. This program is a motion simulation program that will enable accurate moment arms to be determined from the data collected from each subject. The shoulder model includes bony segments for the thorax including the rib cage, clavicle, scapula, and humerus. The different components of the trapezius and the serratus anterior were separated out, as well as their origins and insertions, and each element aligned in the model. The model allows the user to wrap the muscles around the bony surfaces using wrapping algorithms and provides the calculation of the muscles' moment arm. The kinematics of individual subjects can be taken into account and the bony segments can be moved accordingly to three-dimensional positions and orientations.

Data Reduction

Employing the SIMM model, we were able to determine the moment arms of each muscle component using the subject data sets. Baseline data from the MotionMonitor™ program is used to set up a local coordinate system for each segment under study. Therefore each subject's humerus, clavicle, scapula, and thorax will have simulated coordinate systems in the SIMM program. A plane can be developed by digitizing three known landmarks on each segment representing three unique three-dimensional points. These points are used to orientate the systems to the location of the sensors on the individual segments. In other words, each sensor will now represent a body's segment in relation to known anatomical landmarks instead of an undefined point in space. Two of these digitized points are usually used to define the first axis, other digitized points in the plane will determine the orientation of the second axis, and the third axis is aligned perpendicular to the previous two.

With the sternal notch as the origin, the coordinate system for the thorax was in line with the cardinal planes of the body in a standing position with Z running superiorly (positive), Y extending anteriorly (positive), and X laterally. The scapula's coordinate system aligned X(S) from the root of the spine of the scapula to the AC joint (pos), the Y(S) axis extends anteriorly perpendicular to the plane of the scapula. Z(S) was aligned superiorly perpendicular to the previous two axes. The humeral Z(H) is in line with the long axis of the humeral shaft. Y(H) is directed perpendicular to Z(H) anteriorly using the medial and lateral epicondyles as references. X(H) is perpendicular to Z(H) and Y(H) laterally. The clavicle's axes are aligned from the sternoclavicular joint inferiorly (Z), anteriorly, (Y), and laterally (X) through the acromioclavicular joint.

Clinically relevant clavicular rotations are therefore described as protraction/retraction about the Z axis, depression/elevation about the Y axis, and anterior/posterior rotation about the long-axis (X) of the clavicle. These axis are added in the order Z,Y,X when relating data to a three dimensional coordinate system. Scapular rotations of anterior/posterior tipping are about the X axis, with anterior tipping consisting of the superior portion of the scapula moving anteriorly. Upward/downward rotations about the Y axis are described in reference to the glenoid. Medial/lateral rotation about the Z axis is described as the glenoid moving in an anterior direction during medial rotation. The coordinates are added in the order X,Y,Z. Humeral rotations about the Z axis are internal/external rotations, abduction/adduction rotations are about the Y axis, and flexion/extension rotations are about the X axis. These motions are summed in the order Z,Y,X. Data collected from the MotionMonitor™ system is used to find individual moment arms for each muscle element of the trapezius and serratus anterior about each axis. Then through the SIMM program, we are able to find moment arms corresponding to each axis, fascicle, and motion.

Data Analysis

Before averaging across repetitions, the reliability of the potential forces for each repetition needed to be assessed. Intraclass Correlation Coefficients (ICC) were used to determine the reliability of the potential forces across the two repetitions for each of the UT, MT, and LT for the first five subjects. The values for each moment arm at each angle of elevation (30°, 60°, 90°, and 120°) and each muscle during scapular plane abduction were analyzed using separate one-way ANOVA’s with subjects as the factor.

ICC values were calculated using the following formula from the ANOVA outputs of each combination of variables: $ICC=(BMS-WMS)/[BMS+(k-1)WMS]$[16]. These values were used to determine the reliability for each subject between repetitions of scapular plane abduction.

Reliability was further tested with standard error of measurement (SEM). SEM is a reliability measure that was used to find the standard error for the repeated repetitions[16]. This was calculated using the formula: $SEM=\sqrt{MSe}$[16]. The mean squared error (MSe) was taken from the ANOVA outputs of each angle and moment arm. For subsequent analyses the averages of the two trials were used.

Normality of the data was analyzed for skewness and kurtosis of each dependent variable across the conditions of angle and moment arm, and normality was accepted. For the first, second and fourth hypotheses, 2-way ANOVAs were used to analyze the effects of the independent variables of moment (clavicular elevation, retraction, and rotation) and angle (30, 60, 90, and 120) on the dependent variables of upper and lower trapezius. Although not hypothesis driven, the same analysis was used for middle trapezius. For the third hypothesis, a 2-way ANOVA was also performed to determine the effects of the independent variables of angle (30, 60, 90, and 120) and muscle section (middle and lower trapezius) on the dependent variable of posterior tipping moment of the scapula. This analysis was also repeated for the remaining motions of upward rotation and internal rotation. In the presence of a significant interaction effect, post-hoc analysis was completed using Tukey-Kramer adjustments. The factor of primary interest was assessed at each level of the interacting factor. In addition to testing the hypotheses, the effects of the independent variables of moment (acromioclavicular upward rotation, internal rotation, and tipping) and angle (30, 60, 90, and 120) on the dependent variables of middle trapezius and lower trapezius were analyzed by running 2-way ANOVAs for each dependent variable. For all statistical analyses, a p-value less than .05 was considered significant. All statistics were analyzed using NCSS 2000 software.

Results

For the reliability analysis, significant ICC values were obtained between trials for every angle, moment arm, and muscle ranging from 0.70-0.99. The SEM values ranged from 0.005 to

1.25 Nm (Table 1). The two trials for each subject demonstrated high (good to excellent) reliability.

The two-way ANOVA of moment direction by humeral angle for UT demonstrated a significant interaction ($F = 2.75$, $df = 8$, $p = 0.011309$). The UT produced a clavicular elevation moment throughout the range of motion evaluated (13.2 Nm on average). The ANOVA results displayed in Figure 1 and Table 2 showed that the ability of the UT to elevate the clavicle (Hypothesis 1) was the lowest at rest. The torque capabilities increased as the angle of SAB increased with the greatest torque being produced at 120°. Post-hoc analysis demonstrated a significant difference between rest and all other angles, whereas 120° of SAB was only significantly different from rest, 30°, and 60° (Table 2). The UT's ability to retract the clavicle increased slightly but significantly from rest to elevated arm positions (Figure 1 & Table 2). The UT's ability to anteriorly rotate the clavicle progressively increased as humeral elevation increased (Figure 1 & Table 2).

When comparing across moment directions (Figure 1), the ANOVA results displayed that the UT has its greatest torque capabilities as an elevator of the clavicle followed by retraction and then anterior rotation (Hypothesis 4). Post-hoc analysis showed significant differences between these three moment arms at each angle of elevation (Table 4).

The ANOVA for MT also demonstrated a significant interaction of moment direction and humeral angle ($F = 49.92$, $df = 8$, $p = 0.000000$). The torque capabilities of the MT to externally rotate the scapula undergo no significant changes from rest to 120°. Figure 2 shows it stays fairly consistent across angles, showing no definite trend. The ability of the MT to upwardly rotate the scapula decreased as the angle of SAB increased from rest to 120°, with significant differences occurring between all angles of elevation (Figure 2). With regards to anterior tilting of the scapula, the torque producing capabilities of the MT increased as SAB elevation angles increased from rest to 120°, with a significant difference between rest and 120° (Figure 2).

When comparing across moment direction, the ANOVA results illustrated that the MT is primarily an external rotator of the scapula through all angles of SAB. At rest, the MT has a greater ability to upwardly rotate the scapula than to anteriorly tilt it. However, with increasing angles of SAB, the MT develops a greater ability to produce anterior tilt (Figure 2).

The ANOVA results for LT again demonstrated a significant interaction of moment direction and humeral angle ($F = 80.30$, $df = 8$, $p = 0.000000$). Figure 3 displayed a trend towards a decrease in posterior tilting capabilities of the LT as angle of SAB increases (Table 3). However, post-hoc analysis showed no significant difference between angles (Hypothesis 2). When considering external rotation of the scapula, Figure 3 shows a trend toward increased external rotation moment as well, but post-hoc analysis showed no significant differences between angles of SAB. The ability of the LT to upwardly rotate the scapula progressively decreased between the angles of rest and 120° with significant differences between all angles of SAB (Figure 3).

At rest, the LT has a greater ability to upwardly rotate the scapula than to externally rotate it. However, with increasing angle of SAB, the LT develops a greater ability to externally rotate than upwardly rotate the scapula. Across all angles of SAB, the LT has the least ability to posteriorly tilt the scapula (Figure 3).

When comparing the MT and LT, the ANOVA results showed that the LT has a greater ability to posteriorly tilt the scapula (Hypothesis 3). Post-hoc analysis demonstrated significant differences between these divisions at all angles of SAB (Figure 4, Table 3). Figure 5 illustrated that the LT is consistently a greater upward rotator of the scapula than the MT, which actually becomes a slight downward rotator at high angles of SAB. Again post-hoc analysis demonstrated significant differences between the upward rotation capabilities of the MT and LT divisions at all angles of SAB (Figures 5, Table 3). Lastly, when considering external rotation, the LT has greater torque capabilities than the MT with significant differences at all SAB elevation angles (Figure 6, Table 3).

Discussion

The shoulder complex is a complicated region consisting of three segments and four articulations which move in succession and are dependent upon each other. The manner in which these segments and articulations move together is controlled by the torque capabilities and actions of the scapular musculature. Scapular torques and scapular kinematics occur in three-dimensions and therefore, cannot be adequately described with two-dimensional analysis. A greater understanding of how the scapular muscles affect the three-dimensional kinematics of shoulder complex will allow physical therapists and other health care providers to more effectively treat shoulder pathologies such as acromial impingement.

Our hypothesis that the upper trapezius's capability to elevate the clavicle will decrease during increasing angles of SAB and therefore decrease its ability to upwardly rotate the scapula was not supported. However, the data indicates that our second and third hypotheses were supported . The torque capability of the lower trapezius to posteriorly tilt the scapula did decrease during SAB with the lower trapezius contributing more to posterior tipping of the scapula than the middle trapezius during SAB. Finally, our prediction that the upper trapezius would have a greater ability to produce clavicular elevation than retraction or posterior long-axis rotation secondary to its insertion on the distal clavicle was also supported.

In 1988, Bagg and Forest described the scapula's instantaneous center of rotation (ICR) as moving from the spine of the scapula laterally towards the acromioclavicular joint during abduction of the arm. They hypothesized that as the ICR moved, the LT's moment arm would increase during abduction due to the shift in the ICR away from the spine of the scapula producing a larger moment arm[1]. Our results contradict this theory as we found the LT's ability to upwardly rotate the scapula to be the greatest at lower angles of elevation and consequentially decrease with increased angles of SAB. Because our study used the SC and AC joints as independent centers of rotation, we were able to determine the LT's effects on the scapula independently of the clavicle.

Bagg and Forest also theorized that the UT and lower serratus anterior would have larger force arms for scapular upward rotation than the MT and LT[1]. Due to its insertion the UT's greatest potential is to produce retraction and elevation of the clavicle. These effects on the clavicle also create a slight ability to upwardly rotate the scapula indirectly through the AC joint. Our results show that the MT and LT are able to create much more substantial moments for upward rotation of the scapula through their direct insertions with their largest potential occurring at early ranges of scapular plane abduction.

Several authors have previously stated that the actions of the UT and LT act together to upwardly rotate the scapula and therefore aid in raising the arm. However after noting that the upper portion of the trapezius (UT) inserts distinctly on the distal end of the clavicle, Johnson[2] proposed that it could not contribute substantively towards scapular upward rotation. It has been shown that clavicular elevation and anterior rotation translate into scapular upward rotation at varying degrees. Therefore the elevation that is potentially produced by the UT is able to result indirectly in some scapular motion. The UT's potential forces primarily act to elevate and retract the clavicle with limited potential ability to rotate the scapula.

Based on the orientation of fibers of the trapezius, Johnson[2] states that the (middle) trapezius fibers are able to draw the scapula medially but are not able to elevate the scapula directly. Once again, the fibers of the UT are unable to directly affect motion of the scapula, however our results show the MT is able to produce predominantly external rotation moments (scapular rotation towards midline). The LT also has potential to produce more external rotation torque than upward rotation or posterior tilting.

In general our findings are in agreement with Johnson's[2] descriptions of the line of action of the UT. Our results of the UT's potential to move the clavicle and scapula contradict previous theories involving a force couple. Our descriptions of the primary actions of the MT and LT are largely in agreement with the previous body of knowledge that suggests they are predominately external rotators of the scapula. Our results show little evidence to suggest that the LT has potential for posterior tilting due to the MT's competing actions. The LT does however have a substantial ability to upwardly rotate the scapula however this potential decreases through range.

To our knowledge, measurement of the potential forces of the trapezius muscle through direct 3-dimensional in vivo techniques has not been previously described in the literature.

Our results showed that the UT has its greatest ability to produce elevation of the clavicle, followed by retraction and then anterior rotation. Anterior rotation of the clavicle will produce anterior tipping and downward rotation of the scapula. However, our results showed that the ability of the UT to cause anterior rotation of the clavicle is negligible. As a result the amount of anterior tipping and downward rotation of the scapula that may occur due to this clavicular motion will be very small. Therefore, it appears that the primary motions that the UT causes at the scapula through the clavicle are retraction, anterior tilting, and some upward rotation.

By our results, it also appears that the MT functions primarily as an external rotator of the scapula, and this ability remains fairly constant across all angles of elevation. At rest, the MT also displays the ability to cause upward rotation and anterior tilting of the scapula. With increasing angles of humeral elevation in the scapular plane, the ability of the MT to anteriorly til the scapula increases slightly. At the same time, its ability to cause upward rotation of the scapula decreases. At high angles of humeral elevation in the scapular plane, the MT actually appears to become a slight downward rotator of the scapula.

At rest, the LT appears to have its greatest ability to produce upward rotation of the scapula, followed by external rotation and then posterior tilting of the scapula. However, as the angle of scapular plane abduction increases, the ability of the LT to upwardly rotate the scapula progressively decreases while its ability to externally rotate the scapula increases slightly. The ability of the LT to cause posterior tilting of the scapula decreases as scapular plane abduction increases, with this ability decreasing to almost zero at the highest angles of elevation in the scapular plane.

When comparing the MT and the LT, our results showed that the LT is a much stronger potential external rotator of the scapula than the MT. Furthermore, the ability of the MT to cause external rotation of the scapula remained fairly constant across increasing angles of scapular plane abduction while the LT's ability increased slightly with increasing angles of elevation with the greatest increase occurring from rest to 30 degrees of scapular plane abduction. Regarding tilting of the scapula, at rest the MT acts as an anterior tilter of the scapula while the LT acts as a posterior tilter of the scapula. As previously stated, the tilting ability of the LT decreases to nearly zero with increasing angles of scapular plane abduction. Conversely, the ability of the MT to cause anterior tilting of the scapula increases slightly with increasing angles of scapular plane abduction. Both the MT and LT act as upward rotators of the scapula at rest, with the LT having a much greater torque producing potential than the MT. However, as the angle of scapular plane abduction increases, both the LT and MT progressively lose ability to cause upward rotation of the scapula, with the MT even becoming a slight downward rotator at the highest angles of scapular plane abduction.

When interpreting our results, it is important to remember that the potential torque producing capabilities that we present are calculated as if all parts of the trapezius are fully activated at an equal level. Although this is not the case during our normal activities of daily life, the ratio of relative activity of the different divisions of the trapezius will remain fairly constant and we can use the ratios in conjunction with EMG data to evaluate the relative contributions of the different parts of the trapezius during different activities. For example, Bagg and Forrest[17] found that the activation of the UT gradually increases during the beginning phase of abduction of the humerus, while the LT is not substantially activated until approximately 90 degrees of abduction. Combined with our results, this may show that the UT is working more during the first 90 degrees of scapular plane abduction to elevate the clavicle and causing very little upward rotation of the scapula (setting phase), while the LT may be working more during the middle and late phases of scapular plane abduction to produce upward and external rotation moments on the scapula.

When developing a rehabilitation program for patients with shoulder injuries, abnormal scapular kinematics are often of concern. By using our data, which describes which parts of the trapezius contribute most to certain scapular motions, we can help treat and prevent these imbalances by focusing on strengthening the part of the trapezius that actually controls the motion we want to correct. At the same time, it is important not to exacerbate muscle imbalance by simultaneously strengthening a different part of the trapezius that may help contribute to already abnormal scapular kinematics.

It is believed that imbalances in force production between the different parts of the trapezius and serratus interior can lead to shoulder pathology. For example, Ludewig and Cook[5] found increased activation of the UT throughout the entire range of humeral elevation, increased activation of the LT from 60 to 90 degrees and 91 to 120 degrees of humeral elevation, and a decrease in the activation of their lower serratus anterior in subjects with subacromial impingement syndrome. These same subjects also showed decreased scapular upward rotation, increased anterior tipping, and increased scapular medial rotation under loading conditions. It could be that the increased activation noted in the UT and LT was occurring due to an attempt to compensate for the decreased activation of the serratus anterior, which may have caused the decrease in upward rotation of the scapula. Furthermore, the increased activation of the UT may have led to the increase in anterior tipping of the scapula.

Conclusion

The UT is primarily a clavicular elevator and retractor throughout the range of scapular plane abduction. Due to the angle between the clavicle and scapula, the UT indirectly produces slight anterior tilting and upward rotation (via clavicular elevation) and retracts (via clavicular retraction) the scapula. The MT primarily acts as an external rotator of the scapula consistently through elevation in the scapular plane. The LT initially has its greatest potential torque capabilities as an upward rotator of the scapula. However, this capability gradually decreases as the angle of elevation increases. At humeral elevation angles greater than 30 degrees, the LT has its greatest potential for producing external rotation of the scapula. Throughout SAB, the LT consistently has a greater potential ability than the MT to produce external rotation and upward rotation of the scapula. However, the MT produces anterior tilt while the LT actually posteriorly tilts the scapula. This information can now be used in developing interventions for shoulder pathologies such as subacromial impingement syndrome.

References

1. Bagg SD, Forrest WJ: A Biomechanical Analysis of Scapular Rotation during Arm Abduction in the Scapular Plane. *Am J Phys Med Rehabil,* 1988; 67: 238-45

2. Johnson G, Bogduk N, Nowitzke A, House D: Anatomy and actions of the trapezius muscle. *Clin Biomech,* 1994; 9: 44-50

3. Inman VT, Saunders JB de CM, Abbott LC: Observations on the function of the shoulder joint. *J Bone Joint Surg (Am)*, 1944; 26:1-30

4. Michener LA, McClure PW, Karduna AR: Anatomical and biomechanical mechanisms of subacromial impingement syndrome. *Clin Biomech,* 2003; 18:369-379

5. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Phys Ther,* 2000; 80 (3), 276-291.

6. McClure PW, Michener LA, Sennett BJ, Karduna AR. Direct 3-dimensional measurements of scapular kinematics during dynamic movements in vivo. *Journal of Shoulder and Elbow Surgery,* May/June 2001; 10(3):269-277.

7. Borstad JD, Ludewig PM. Comparison of scapular kinematics between elevation and lowering of the arm in the scapular plane. *Clinical Biomechanics.* 2002; 17: 650-659.

8. Veeger HEJ, van der Helm FCT, Chadwick EKJ, Magermans D. Toward standardized procedures for recording and describing 3-D shoulder movements. *Behavior Research Methods, Instruments, & Computers,* 2003; 35(3):440-446.

9. Halder AM, Itoi E, An K. Anatomy and biomechanics of the shoulder. *Orthopedic Clinics of North America*, 2000; 31(2):159-176.

10. Levangie PK, Norkin CC. Joint Structure and Function: A Comprehensive Analysis. 3rd ed. Philadelphia: F. A. Davis Company, 2001.

11. Kardura AR, McClure PW, Michener LA, Sennett B: Dynamic Measurements of Three-Dimensional Scapular Kinematics: A Validation Study. *Journal of Biomechanical Engineering* 2001; 123:184-190

12. Lukasiewicz AC, McClure PW, Michener LA, Pratt N, Sennett BJ. Comparison of three-dimensional scapular position and orientation between subjects with and without shoulder impingement. *J. Orthop. Sports Phys. Ther.* 1999; 29, 574-583.

13. Vecchio P, Kavanagh R, Hazleman BL, King RH. Shoulder pain in a community-based rheumatology clinic. *British Journal of Rheumatology.* May 1995; 34(5): 440-442.

14. Wadsworth DJ, Bullock-Saxton JE. Recruitment patterns of the scapular rotator muscles in freestyle swimmers with subacromial impingement. *International Journal of Sports Medicine.* November 1997; 18(8):618-24.

15. McQuade KJ, Dawson J, Smidt GL. Scapulothoracic muscle fatigue associated with alterations in scapulohumeral rhythm kinematics during maximum resistive shoulder elevation. *Journal of Orthopaedic & Sports Physical Therapy*. August 1998; 28(2):74-80.

16. Portney and Watkins. *Foundations of Clinical Research 2nd Ed.* Prentice-Hall 2000.

17. Bagg SJ, Forrest WJ. Electromyographic study of the scapular rotators during arm abduction in the scapular plane. *American Journal of Physical Medicine.* 1986; 65(3): 111-124.

Literature Reviews

Brandon Busch
McClure PW. Michener LA. Sennett BJ. Karduna AR. Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. [Evaluation Studies. Journal Article] *Journal of Shoulder & Elbow Surgery. 10(3):269-77, 2001 May-Jun.*

This study sought to build on the body of knowledge relating to scapular movement. Another purpose was to compare data collected against other studies that used surface measurements as well as 2-dimensional data to the direct measurements taken in vivo with this study. This new data would then be used to determine the accuracy (or error) of scapular movement using less invasive techniques. The researchers justified the study with the hopes of benefits in treatments of pathologies regarding irregular scapular movements. They hoped that the in vivo measurements would enhance the accuracy of measurements in the shoulder complex. I was unable to locate a clear hypothesis.

The study used eight volunteers (5 men, 3 women) who exhibited healthy shoulders. The study included inserting metal pins into the spine of the scapula and attaching other sensors on the humerus (via a cuff) and the thoracic spinous process of T3 with tape. The subjects then conducted three movements while data was collected in the scapular plane elevation (abduction in the scapular plane), flexion, and internal/external rotation of the humerus with arm in a 90-90 position in the frontal plane. Scapular elevation showed upward rotation, posterior tilting, and external rotation. Flexion was similar. External and internal rotation showed little scapular rotation until the arm reached end range. Near end range of external rotation the scapula upwardly rotated, posteriorly tilted and externally rotated.

Some limitations are discussed including the great variability in previous studies, a small sample set, slow arm speed during test, and a possibility that the pins could have interfered with the results.

This study seemed to strive for accuracy in the measurement of scapular movement through the use of in vivo techniques (inserting pins directly in scapula). Although I‘m sure a great deal of good will come from the results, I would still question the necessity of this invasive procedure. The results in general terms seemed fairly consistent with previous studies which would lead me to again question the study’s necessity.

Craig Dom
Ludwig, P.M.; Cook, T,M. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Physical Therapy*. 80(3):276-91, 2000 Mar.

The stated purpose of this study was to "analyze glenohumeral and scapulothoracic kinematics and associated scapulothoracic muscle activity in a group of subjects with symptoms of shoulder impingement relative to a group of subjects without symptoms of shoulder impingement matched for occupational exposure to overhead work." Justification of the study includes the statistics that approximately one-third of shoulder complaints are related to rotator cuff problems, and most of these people contribute their pain to work and sport related activities that require frequent overhead work with their arms. It has been shown that such positions, as overhead arm work, are a risk factor for shoulder tendonitis and other shoulder pain.

This study investigated four hypotheses. The first of which compared the kinematics of the scapula and humerus of the two groups. The researchers hypothesized that they would find a decrease in scapular upward rotation, scapular posterior tipping, and humeral lateral rotation, and an increase in scapular medial rotation in subjects with shoulder impingement during humeral elevation. The second hypothesis stated that subjects with shoulder impingement would present with increased upper trapezius EMG activity and decreased lower trapezius and serratus anterior EMG activity while performing humeral elevation. The third hypothesis proposed that these changes would be consistent through all phases of the painful arc. The fourth hypothesis stated that these kinematic differences between the groups would be greater with the application of hand held loads.

This study involved 52 construction worker volunteers (sheet metal and carpentry workers) who are exposed to routine work at or above shoulder level. The experimental group subjects were required to have a history of pain in the anterolateral shoulder for more than one week, painful are of movement, painful palpation, positive impingement signs, and shoulder abduction of at least 130 degrees. All assessments were performed by the same researcher. All subjects were male and were asked to fill out a Shoulder Pain and Disability Index. EMG data was collected using differential preamplified silver- silver chloride surface electrodes and collected at a 300 Hz sampling rate. The electrodes were placed on the upper and lower trapezius muscles as well as the serratus anterior. A reference was placed on the distal ulna of the wrist.

The 3-D kinematics were tracked with the Polhemus FASTRAK electromagnetic motion capture system. These sensors were placed on the sternum and the acromion process. The third was secured to the distal humerus with a Velcro cuff. Subjects were then asked to perform humeral elevation with their dominant shoulder in the scapular plane at one complete cycle every 4 seconds. EMG and kinematic data was collected for both non-loaded and loaded conditions.

Shoulder impingement subjects experienced decreased upward rotation of the scapula during the first phase (30-60 degrees) of humeral elevation. The impingement group also displayed increased scapular medial rotation under the load conditions. This group also displayed movement toward a more anteriorly tipped position as elevation progressed. Both of these findings supported the hypothesis. However, there was no difference in lateral rotation between the group rather than a decrease in the impingement group as hypothesized. The EMG data showed that upper trapezius activity was only greater in the impingement group during loaded elevation between 60-120 degrees. Contrary to the hypothesis, lower trapezius activity actually increased in subjects with shoulder impingement during 60-120 degrees of elevation. The serratus anterior EMG displayed a decrease in the experimental group during all phases of elevation, which could explain the increased upward rotation of the scapula during this phase. The increased activity of the trapezius may be compensating for the serratus anterior and producing a more normal upward rotation.

Limitations for this study could be the disturbances in the EMG signal, developed compensations in the subjects, relatively low level of impairment compared to the norm, skin slip with the EMG surface sensors, and the non-classification of experimental group subjects. This data would not be well applied to women, the elderly, or people involved in athletic activities due to the demographics of the subjects.

I felt that the article was very clear, and it appeared that many precautions were taken to make the study as accurate as possible. It was well laid out with hypotheses clearly stated, and the results and outcomes were given and addressed well.

Lindsey Laux
Johnson G, Bogduk N, Nowitzke A, House D: Anatomy and actions of the trapezius muscle. *Clinical Biomechanics.* 1994; 9: 44-50.

This paper opens by discussion the inconsistencies that exist among authoritative texts concerning the actions and anatomy of the trapezius muscle. Specifically, the introduction discusses the idea that the cervical trapezius exerts an upward force upon the shoulder girdle even though the direction of the fibers of the trapezius is inconsistent with this. The proposed function of the muscle is not consistent with the anatomy. Because of these issues, the authors of this paper decided to study the anatomy of the trapezius and derive its functions by using this information. They stated that by defining the fascicular anatomy of the trapezius and by determining the possible actions of these fascicles in three dimensions they would be able to determine if its anatomy and morphology went along with the conventional views on the action of the trapezius. This was the purpose of this study.

This was a cadaveric study using seven cadavers, all of whom were over 65 years of age. In two of the cadavers, the cervical trapezius was studied, while the thoracic trapezius was studied bilaterally in three more cadavers. In the final two cadavers, the entire trapezius was dissected bilaterally. The muscle was dissected in such a way as to establish its fascicular anatomy. The authors defined a fascicle as a bundle of muscle fibers with a distinct, identifiable attachment. The fascicles were first detached from their origins (medial attachment), dissected away from the rest of the muscle mass, and then detached from their lateral attachments. The medial and lateral attachments of the muscle were marked by map pins and radiographs of the specimen were then taken. The sites of attachment were also drawn on sketches of the vertebral column and the shoulder girdle. During dissection of the cervical trapezius, wires were laid down along the path of each fascicle. The PCSA of the fascicles were also determined by dividing the length of the fascicle by its volume. The possible functions of the fascicles were derived by studying their orientation from the radiographs and by rebuilding the muscle on the radiograph of the neck and shoulders of a normal, living person.

From this dissection, the authors noted that the fibers of the upper trapezius ran in parallel from the superior nuchal line and the ligamentum nuchae to the posterior border of the distal third of the clavicle. These fascicles approached the clavicle in a nearly horizontal pattern, with only a slight downward deviation. The fascicle from C7 attached on the acromion. Fascicles from C7 and T1 (middle trapezius) approached the acromion and spine of the scapula virtually transversely. The lower fascicles (lower trapezius) all attached on the deltoid tubercle of the scapula in a “fan like” distribution. The fascicle from C7 had the largest PCSA, and the fibers below T1 got progressively smaller. Overall, the fascicles from C3-C6, C7, and T1 made up over half of the total PCSA of the trapezius.

Because the fibers of the upper trapezius insert on the clavicle and not the scapula and because they run mostly transversely, they are not really predisposed to elevate the scapula. Their orientation causes them to act to bring the clavicle backwards/medially, not upwards. Although the upper fibers of the upper trapezius run in a direction that may allow them to elevate the clavicle, they are too small to do so. The transverse orientation of the fascicles from C7 and T1 along with the collectively transverse orientation of the fascicles from the lower trapezius and the upper trapezius dictates that the action of the trapezius in the horizontal plane is to bring the clavicle, acromion, and spine of the scapula backwards/medially.

The authors also discussed the proposed upwards rotation of the scapula by the trapezius. C7 and T1 attach close to the axis of rotation of the scapula, which begins at the root of the spine and moves to the deltoid tubercle throughout the course of rotation. Therefore, the moment arms of C7 and T1 are too short to produce an upward rotational moment, although they are able to contribute to the force couple for upward rotation once the action begins (by serratus anterior) – they do not initiate the action. It is thought that the action of the lower trapezius is to stabilize that axis against upward action by levator scapulae and the lateral action of serratus anterior. The lower trap allows rotation to occur, but it does not contribute any net torque to the action.

The authors state that their observations contradict the traditional portrayal of the actions of the trapezius, specifically the action of upward rotation because the trapezius does not exert an upward force on the scapula. The upper trapezius is able to raise the clavicle and the scapula by rotating the clavicle medially and upwards, but not by elevation. This means that the sternoclavicular joint sustains a large amount of compressive force. These actions of the trapezius are consistent with EMG data.

The paper concludes by stating that two advantages of this mechanism of raising the clavicle and the scapula are that the weight of the upper limb and any weight it carries are borne by the SC joint and not the cervical trap. Secondly, there are no compressive loads on the cervical spine due to the upper limb because only transverse loads are exerted on the ligamentum nuchae.

The authors did not discuss any limitations of their study. However, some possible limitations that may be identified were the fact that only 7 cadavers were studied, and we were not told the gender of the cadavers. Therefore, it may be difficult to apply these results to the whole population. Furthermore, this was a two-dimensional study of the function of the trapezius, and only motions in one plane were studied. Finally, the authors used kinematic data from previous literature and did not derive any of their own.

Alisha Fey

Bagg SD. Forrest WJ. A Biomechanical Analysis of Scapular Rotation during Arm Abduction in the Scapular Plane. *American Journal of Physical Medicine & Rehabilitation. 67(6):238-45, 1988 Dec.*

Looking at the dynamic pattern of scapulohumeral rhythm and the scapular instantaneous center of rotation (ICR) during arm abduction in the scapular plane was the purpose of this study. The researchers justified this study by trying to create a biomechanical model from previous research and electrical activity patterns that would provide a holistic understanding of scapular rotation. The researchers hoped that this model would help improve prosthetic designs as well as assist in diagnosis and rehabilitation of shoulder girdle problems. There is a lot of conflicting data on scapulohumeral rhythm, ICR, and other aspects of the shoulder. Therefore, the researchers compared and contrasted their results to previous findings and used the data to make their model. The researchers did not have a clear cut hypothesis.

Twenty healthy young male volunteers with no history or signs of shoulder or back problems were the subjects. The subjects held their arms at thirteen predetermined positions (15° increments) of arm abduction. The subjects used two vertical guiders that were positioned at 30° anterior to the coronal plane. The root of the scapular spine, the acromial angle, and the inferior angle of the scapula as well as the long axis of the humerus and several spinous processes were used as markers. Each position was filmed and analyzed with a motion analyzer. The scapular and humeral angles and the location of the scapular ICR for each position was measured and analyzed by a program that was developed.

The researchers found that there were three fairly separate patterns of scapulohumeral rhythm (pattern A, B, & C). When plotted, these three patterns show variable slopes, none of which were linear. This shows that the ratio of arm abduction to scapular rotation is dynamic and not constant. The researchers found that the scapular ICR is initially located at the root of the scapular spine. During the middle phase, the ICR migrates from the root of the scapular spine to the acromioclavicular joint. Using electrical activity of the scapular rotators and the data obtained, the researchers made a biomechanical model of the shoulder girdle. From this model and the electrical activity of the muscles, the functions of the parts of the trapezius and the serratus anterior can be evaluated.

One limitation of this study could be the weight of the subjects arm or a subject having a strong, well developed deltoid. These things could provide greater resistance when abducting the arm. Another limitation could be that they used all male subjects, all the subjects were young, and all were healthy. These factors do not necessarily represent the general population. This study was done two-dimensionally which is another limitation. A three-dimensional study looks at all the available motion of the shoulder, thus providing better results. When looking at the lines of action, this study based them on textbook anatomical descriptions. This could be a limiting factor since textbooks may not be accurate. Previous studies have found more accurate descriptions of the lines of actions of the muscles, which would have been a more accurate source to use. Overall, I thought this was a good study. From what they presented, there was a lot of differing data and interpretations of scapulohumeral rhythm as well as the scapular ICR. Therefore, I think this study was necessary and that they did a good job of looking at these things and using past information to come up with a more accurate model of shoulder motion.

Tables and Figures

Table 1: Intraclass Correlation Coefficient (ICC)/Standard Error of Measurement (SEM) Chart

		UT	MT	LT
Clavicle Retraction	ICC	0.96-0.99	0.81-0.98	0.86-0.98
	SEM‡	0.03-0.07	0.07-0.14	0.42-1.18
Clavicle Elevation	ICC	0.97-0.99	0.91-0.99	0.92-0.99
	SEM	0.05-0.10	0.09-0.18	0.23-0.67
Clavicle Rotation	ICC	0.97-0.99	0.89-0.95	0.82-0.89
	SEM	0.005-0.02	0.11-0.20	0.67-1.16
Acromioclavicular IR	ICC	N/A	0.90-0.98	0.99-0.99*
	SEM	N/A	0.07-0.14	0.27-0.40
Acromioclavicular UR	ICC	N/A	0.91-0.96	0.88-0.93
	SEM	N/A	0.17-0.29	0.84-1.25
Acromioclavicular Tilt	ICC	N/A	0.85-.098	0.70-0.99
	SEM	N/A	0.04-0.20	0.16-0.56

‡SEM = Newton-Meters
*Values ranged from: 0.9947-0.9952

Table 2: Hypothesis #1: Clavicular elevation moments of UT

Angle of SAB	Mean (Nm)*	Significantly Different From:
Rest	-12.850	30, 60, 90, 120
30	-13.097	Rest, 90, 120
60	-13.266	Rest, 120
90	-13.348	Rest, 30
120	-13.520	Rest, 30, 60

*Mean potential torque values

Table 3: MT Potential Torque < LT Potential Torque Across Angles

Moment Arm	Degrees of Freedom	F Value	Probability Level
Scapular IR	4	2.86	0.039333*
Scapular UR	4	86.03	0.000000*
Scapular Tilt	4	7.69	0.000184*

*Significant difference (Hypothesis #3 - LT contributes more to posterior tilting of the scapula than MT)

Table 4: Hypothesis #4: UT Post-Hoc Analysis of Interaction

	Angle of SAB	Significantly Different From:
Elevation	Rest	Protraction, Post. Rotation
	30	Protraction, Post. Rotation
	60	Protraction, Post. Rotation
	90	Protraction, Post. Rotation
	120	Protraction, Post. Rotation
Protraction	Rest	Elevation, Post. Rotation
	30	Elevation, Post. Rotation
	60	Elevation, Post. Rotation
	90	Elevation, Post. Rotation
	120	Elevation, Post. Rotation
Posterior Rotation	Rest	Elevation, Protraction
	30	Elevation, Protraction
	60	Elevation, Protraction
	90	Elevation, Protraction
	120	Elevation, Protraction

Table 5: Hypothesis #4: UT Torque Capabilities needed?

	Mean (Nm)*	Significantly Different From:
Elevation	-13.216	Protraction, Post. Rotation
Protraction	-9.996	Elevation, Post. Rotation
Posterior Rotation	-1.228	Elevation, Protraction

*Mean potential torque values across SAB measurements at rest, 30, 60, 90, 120. The torque capabilities of the UT present with statistically significantly change across SAB angles, but magnitude of change is clinically insignificant.