Applied Anatomy and Biomechanics of the Scapula

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APPLIED ANATOMY AND BIOMECHANICS OF THE SCAPULA

by

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Bachelor of Science in Physical Therapy
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Submitted to the Graduate Faculty of the
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This Independent Study, submitted by Garrett T.K. Kennedy in partial fulfillment of the requirements for the Degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

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ABSTRACT

The scapula is the first link in the upper extremity kinetic chain. Analysis of the applied anatomy and biomechanics of the scapular link allows the physical therapist to develop pathomechanical models for shoulder injuries. The current health care trend of developing rehabilitation protocols based on sound anatomical, physiological, and biomechanical principles necessitates a strong background in the structure and function of the shoulder.

The purpose of this review of the literature is to provide a compilation of information regarding scapular anatomy and function. The paper is organized into four chapters. Chapter one discusses the phylogenetic and embryological development of the scapula. Chapter two reviews the scapular bursae and scapulometry. Chapter three reviews the postural and static position of the scapula, analysis of the scapular plane, scapulohumeral rhythm, and scapular biomechanics. There is a current void in physical therapy literature regarding comprehensive scapula anatomy and biomechanics. This paper will fill that void. The paper is designed to educate the therapist on the anatomy and function of the scapula, thus giving the therapist an anatomical and biomechanical background to evaluate current shoulder rehabilitation protocols.
CHAPTER I
INTRODUCTION

Scapular function is probably the least studied biomechanical component of the shoulder complex. The vast amount of information concerning the structure and function of the glenohumeral joint has overshadowed the complexity of scapular biomechanics. Researchers such as Codman, Inman, Saunders, Saha, Neer, and Rockwood have laid down the scientific foundation on which most of our current biomechanical models are based.

This paper is divided into four chapters. Chapter one discusses the phylogenetic and embryological development of the scapula and associated muscles. Chapter two describes the scapular bursae and scapulometry. Chapter three will review posture and static position of the scapula, scapular plane discussion, and scapular biomechanics. Finally chapter four will be a general summary. The purpose of this paper is to review the anatomy and function of the scapula thus formulating an anatomical and biomechanical background for the clinical therapist to evaluate current rehabilitation protocols.
Phylogenesis of the Scapula

To comprehend the role the scapula plays in shoulder motion, one must understand its phylogenetic development. The scapula, more than any other bone in the shoulder complex reflects profound evolutionary adaptations. In the lower animals, such as amphibians, the neck and shoulder began as one segment. Evolution from the amphibian genus to humans noted caudal migration of the shoulder resulting in separation of the neck and shoulder. This caudal movement of the shoulder became a functional adaptation, improving the mobility of the prehensile limb and also provided the species with a better biomechanical advantage for locomotion skills. The scapula originally functioned as a transition bone during the division of the forelimb into the separate neck and shoulder components. As inferior migration of the scapula occurred it allowed the scapula to provide a platform for the humerus, resulting in improved arm mobility.

A study of comparative anatomy provides an insight into the functional demands that have guided the morphological changes of the scapula. The most obvious adaptive change in the scapula is the decrease in the scapular index. The scapular index is a ratio of the length of the scapula, measured by the length of the scapular spine, to the breadth of the scapula, measured by the distance from the superior angle to the inferior angle. This adaptation is better
described as the enhanced growth of the infraspinous fossa in a superior-inferior direction compared to a medio-lateral direction. Increasing the breadth of the infraspinous fossa offers a biomechanical advantage to the scapulohumeral muscles (infraspinatus and teres minor) which function as humeral depressors and external rotators.2

The scapular spine is insignificant in animals lower on the evolutionary scale than mammals. The development of the spine is in response to the upright posture found in orthograde animals.1,4 The acromion which is the lateral portion of the spine has increased in size substantially from pronograde to orthograde animals. In the upright posture the importance of the deltoid's function as a humeral abductor increased greatly.1,2,4 The deltoids broad insertion on the acromion has provided a functional demand that could only be met by increasing the size of the acromion.

The coracoid process has also experienced an increase in mass due to tensile stress and strain demands of the muscular attachments of the pectoralis minor, short head of the biceps brachii, and coracobrachialis.1,2,4

The resting position of the scapula has continued to undergo developmental adaptations. As man became erect the anterior-posterior dimensions of the thoracic cage decreased causing a flattening of the rib cage. The flattening of the thorax forced the scapula to move in a medial direction to
its current position of 45 degrees to the midline, also known as the scapular plane. The medial migration of the scapula repositions the glenoid fossa laterally allowing for greater global positioning of the prehensile limb in humans.

Phylogenesis of Scapular Muscles

The muscles that either insert, originate, or biomechanically effect the scapula are divided into three subgroups: axioscapular, axiohumeral, and scapulohumeral. The axioscapular group consists of the serratus anterior, rhomboids major and minor, levator scapula, and the trapezius. The serratus anterior, rhomboids, and levator scapula all originate from one muscle complex.\(^1,2,4\) The serratus anterior was the base muscle complex for all the axioscapular muscles. The functional and postural demands placed on orthograde animals resulted in anatomical separation of these three muscles.\(^1,2,4\) The levator scapula's separation from the serratus anterior is relatively recent on the evolutionary time scale.

Evolution of the serratus anterior noted a pattern of increased proximal and distal muscle fiber mass while the intermediate fiber mass declined.\(^1,4\) This pattern gave rise to the separation of the serratus anterior from the levator scapula. The serratus anterior in humans is currently composed of three sections. The superior muscle fibers are
well developed and insert into the superiomedial angle of the scapula. The intermediate fibers are comparatively smaller and insert into the length of the scapula's medial border on both the anterior and posterior surfaces.\textsuperscript{5} The inferior fibers are also well developed and insert into the inferior angle.\textsuperscript{1,4} This shaping of the serratus anterior influences the force couples necessary to rotate the scapula. The trapezius, the fourth muscle in the axioscapular group has not undergone significant morphological change.\textsuperscript{1,2,4}

Axiohumeral muscles consist of the pectoralis major, pectoralis minor, and latissimus dorsi. The main morphological adaptation in this muscle group was the separation of a once single pectoralis muscle into its superficial and deep components, the pectoralis major and minor.\textsuperscript{1,2,4} The pectoralis minor's insertion has evolved from a direct insertion on the humerus to its current insertion on the coracoid process. The coracohumeral ligament is an evolutionary remanent of that adaptation.\textsuperscript{4}

Scapulohumeral muscles consist of the supraspinatus, infraspinatus, teres minor, subscapularis, deltoid, and teres major. The supraspinatus muscle has shown a phylogenetic trend towards a decrease in its muscle mass with no corresponding changes in its morphological structure.\textsuperscript{2,4} The infraspinatus, however, not found in lower animals has evolved to comprise approximately five
percent of the total scapulohumeral muscle mass in humans.\textsuperscript{1,2,4} The increase in the infraspinatus mass is due to the increased demand for humeral depression and rotation in the prehensile limb. The previously mentioned increased breadth of the infraspinous fossa provides a larger surface area for the origin and increased muscle mass of the infraspinous muscle. The subscapularis muscle mass has also increased over time, currently comprising approximately twenty percent of the total scapulohumeral muscle mass.\textsuperscript{1,2,4} The increased muscle mass of the subscapularis is a direct result of the increased superior-inferior dimension of the scapula, which enlarged the subscapularis fossa.

The most noticeable phylogenetic change in the scapulohumeral muscle group occurred in the deltoid muscle. The deltoid’s muscle mass has increased throughout the period of evolution to its current percentage of forty one percent of the total scapulohumeral muscle mass.\textsuperscript{1,2,4} This increase corresponds to the increased demands placed on the deltoid to function as a primary abductor of the humerus in the orthograde animal. In lower species the origin of the deltoid was continuous from the spine of the scapula to the inferior angle. Through evolution, the inferior portion of the deltoid has developed into the teres minor, thus explaining the common innervation by the axillary nerve.\textsuperscript{2}

The teres major and the latissimus dorsi arose from the same muscle sheet.\textsuperscript{1} Again, the anatomical seperation of
these two muscles was due to new postural and functional demands placed on the original muscle sheet through evolutionary developments. A recent study by Kato\textsuperscript{6} shows that the scapulohumeral muscles plus the latissimus dorsi may have arose from a common cervical myotome. His conclusions were based on anatomical studies of nerve position and development.

**Embryological Development of the Scapula**

The embryological development of the scapula follows the same caudal migration pattern found in the phylogenetic evolution of the human scapula. The scapula initially lies between C4 and C5. During the sixth week the scapula undergoes significant enlargement and moves inferiorly to a position between C4 and T7. By the seventh to ninth week the scapula arrives at its permanent resting position between T2 and T7.\textsuperscript{1,2}

Corresponding to the embryological development of the scapula is the development of the muscles that attach to the scapula. The scapular muscles and their associated nerves are pulled in an inferior direction as the scapula migrates inferiorly. Consequently the axioscapular muscle fibers run in an inferior direction and the brachial plexus is located inferiorly to its contributing nerve roots. The scapula may fail to descend during development, this pathological process is called Sprengels deformity.
Throughout the embryologic, fetal, and postnatal development the scapula is undergoing ossification of its 8 ossification centers. Complete ossification of the scapula is concluded around the twenty second year of life. Abnormal ossification of the acromion may persipitate an impingement syndrome. A relationship between the acromion's shape and the pathology of subacromial impingement exits; but the direct correlation between acromion shape and abnormal ossification is unproven.

The evolution of the scapula is not a haphazard process but a process that is guided by the ever changing functional demands of the evolving forelimb. When we look at the anatomical structure of a human scapula we must remember that we are looking at a snapshot in time of an evolving structure. By studying the phylogenetic and embryological development of the scapula we can see structural changes and trends. It is the understanding of both the past and current morphology that gives us a basis to develop biomechanical models for scapular function.
Bursae

There are several bursae associated with the scapula. In the literature, bursae are described in two ways. The first type of bursa is the one that communicates with the glenohumeral joint capsule. This type of bursa is actually an outpouch of the synovial membrane from the joint. An example of a communicating bursa is the subscapular bursa. The subscapular bursa is formed by the outpouching of the synovial membrane through the anterior recess between the superior and middle glenohumeral ligaments. The subscapular bursa acts to protect the subscapularis tendon from the neck of the scapula and the coracoid process. An inflamed subscapular bursa has been linked to painful crepitation of the scapula during shoulder elevation. The second type of bursae do not communicate with the glenohumeral joint. There are numerous bursae of this type around the scapula. The most commonly associated noncommunicating bursa of the shoulder is the subacromial bursa. The subacromial bursa is implicated in the impingement syndrome. The subacromial bursa provides a
friction free surface for the deltoid muscle to glide over the humeral head while providing a cushion under the acromial arch.

There are many other lesser studied bursae around the scapula. Each of the following muscles have bursa located near their insertion on the humerus; deltoid, pectoralis major, latissimus dorsi, and teres major.\(^1\) Two other bursa that are sometimes involved in the "snapping scapula syndrome" are the infraserratus bursa located between the inferior angle and the thoracic wall, and a bursa located between the superomedial angle and the thoracic wall.\(^1\) Other bursae are located between the infraspinatus muscle and the posterior joint capsule\(^2\); between the serratus anterior and the lateral thoracic ribs\(^10\); at the base of the scapular spine where the trapezius inserts; and between the teres minor and long head of the tricep. There is significant clinical relevance of knowing whether the effected bursa you are treating is communicating or noncommunicating. The placement of the modality may have to be directed towards the joint as well as the bursa in the case of the communicating bursa.

**Scapulometry**

The geometric anatomy is important in understanding the biomechanics of the scapula. Most of the literature
regarding geometric analysis of the scapula relates to two areas, the volume of the supraspinatus outlet and the anthropometric measurement of the glenoid fossa.

The supraspinatus outlet refers to the space between the humeral head and the inferior surface of the acromion. The current pathomechanical model for shoulder impingement revolves around the idea that some soft tissue or boney structure will reduce the supraspinatus outlet space thus causing the impingement syndrome. Petersson and Redlund-Johnell found the supraspinatus outlet measurements in men to range from 6.6-13.8mm, women 7.1-11.9mm, and the total averaged sexes range was from 9-10mm. Petersson and Redlund-Johnell measured the supraspinatus outlet with an anterior-posterior x-ray. Mallon et al. found the outlet to range from 7 to 29.5mm when measuring the supraspinatus space using a Y-scapular view, portraying a lateral view of the outlet. Petersson and colleagues concluded that a supraspinatus outlet measurement of less than 5 mm was always considered pathological.

Bigliani and Morrison proposed that the shape of the acromion was a factor in the reduced volume of the supraspinatus outlet. They developed a three group classification system for the shape of the acromion. Type I acromion have flat undersurfaces, Type II have curved undersurfaces, and Type III acromion have hooked or angled undersurfaces. Further studies by Bigliani and Morrison
showed that eighty percent of people with rotator cuff tears had a Type III acromion. The research of Mallon et al.\textsuperscript{13}, which measured the angle between the anterior and posterior axes of the acromion, supports to a large extent Bigliani and Morrisons classification system. They found the acromion angle to range from 10-66 degrees in the acromion population they studied. The only finding of Mallon’s that was contrary to Bigliani and Morrisons classification system was that no perfectly flat or Type I acromion were found.

The glenoid fossa has been studied extensively in its relationship to shoulder instability. The glenoid fossa has been described as pear shaped or as an inverted comma. Mallon and associates\textsuperscript{13} measured the sagittal (transverse) diameter to be 24mm and the coronal (vertical) diameter to be 35mm. Sarrafian’s\textsuperscript{14} research produced similar results to Mallons thus confirming the average diameter of the glenoid. Studying the relationship between the fossa and the scapular blade, reveals that the fossa is not perpendicular to the blade. The lack of a perpendicular relationship classifies the glenoid fossa as either retroverted (posteriorly tilted) or anteverted (anteriorly tilted). Saha\textsuperscript{15} reports that the normal shoulder is retroverted 7.4 degrees 75 percent of the time and 2-10 degrees anteverted 25 percent of the time. Mallon et al.\textsuperscript{13} found that with different imaging views the anterior-posterior tilt measurement varied significantly. With axillary lateral x-rays, the mean was 2
degrees of retroversion while on the CT pneumoarthrogram the mean was 6 degrees of retroversion.

A more detailed look at the anterior posterior tilt of the glenoid was done by Randelli and Gambrioli. They determined that the amount of retroversion or anteversion depends on what part of the fossa one looks at. The fossa was divided into three sections; upper, middle, and lower. The upper section had a range of retroversion measurements from 2-15 degrees with a mean of 5 degrees. The middle section ranged from 0-8 degrees with a mean of 2 degrees. Finally in the lower section the retroversion range was from 2-15 degrees with a mean of 7 degrees. It is important that the lower section have greater retroversion because it plays the most important role in shoulder stability.

Researchers have tried to link anterior and posterior instability to the degree of anteversion or retroversion of the glenoid fossa. Studies by Cyprien et al. and Randelli and Gambioli found this hypothesis untrue.

Another area of debate regarding the geometric analysis of the glenoid fossa is whether the fossa faces a superior or inferior direction when the arm is in the dependent position. Two different reference points must be used if this question is going to be answered. First we must look at the glenoid fossa in relation to the scapula regardless of its resting position on the thoracic wall. With this reference point in mind, we divide the fossa into superior
and inferior sections. The superior section tilts superiorly about 3-5 degrees.\textsuperscript{18} When you take into account the second reference point, namely what is the orientation of the scapula on the thoracic wall when the arm is in the dependent position, the fossa points in a inferior direction. This second reference point is called the scapular carrying angle. Freedman and Munro\textsuperscript{19} found that 80 percent of all glenoid fossa’s face in the inferior direction by about 5 degrees. Mallon et al.\textsuperscript{13} found the same downward facing fossa with a mean of 4 degrees. These findings of an inferiorly facing glenoid fossa bring into question Basmajian and Bazant theory that the upward facing fossa in conjunction with the tension of the superior part of the capsule prevents downward dislocation of the humeral head on the glenoid fossa.\textsuperscript{20}

It has been through the detailed study of the scapula’s anatomical structure that researchers have learned about the biomechanical forces that control shoulder motion.
CHAPTER III
BIOMECHANICS OF THE SCAPULA

This chapter will discuss scapular function in terms of its postural or static position, scapular plane analysis, and scapular biomechanics. Understanding the basic shoulder biomechanical model is necessary to comprehend the biomechanical contribution of the scapula. The scapula is the first link in the kinetic chain of the upper extremity. Shoulder pathologies can be detected by an analysis of the scapular link from its postural position through its varying dynamic positions.

The resting or postural position of the scapula provides baseline information from which dynamic scapular movements are compared. The amount of variation in the anatomical measurements that define the resting position depends on several factors. Factors such as sex, age, disease state, and arm weight all contribute to the large amount of variation found between individuals.

The scapula's resting position is located on the posteriomedial thoracic wall. The superior angle rests at a point approximately around the 2nd thoracic vertebra. The spine of the scapula is located at the spinous process of
If a direct line was drawn medially from the inferior angle it would cross the spinal column between the spinous process's of the 7th and 8th thoracic vertebra.\textsuperscript{22}

The distance between the spinous process and the medial border of the scapula is called the axioscapular distance. The mean axioscapular distance in nonpathological shoulders ranges from 5-9 cm.\textsuperscript{7,21,22,23} The variation can be explained by one of several theories. First, there is a normal amount of variation found between individuals. Second, the difference in landmarks used to measure the axioscapular distance varied in studies from the use of C7 and T3 as spinal landmarks to the use of the base of the scapular spine and inferior angle as the scapular landmarks. Third, some studies used manual tape measurements while others used measurements derived directly from x-rays. The huge variation found in axioscapular distances bring into doubt the use of axioscapular measurement norms as a tool to predict pathology. The 5-9 cm average for axioscapular measurements does not provide the whole picture. The 5-9 cm measurements were the range for the means between different studies not the range of raw scores. This means that several people had significantly larger axioscapular distances and still were not considered pathological.

The carrying angle of the scapula refers to the amount of scapular rotation either upward or downward. The angle
is calculated by determining the angle between the glenoid fossa and a vertical line. In the 1950’s Basmajian et al. determined that the glenoid tilted in a superior direction or in other words the scapula was rotated upward when the arm was in the dependent position. They postulated this upward rotation in conjunction with the tension of the superior part of the glenohumeral capsule prevented inferior dislocation of the humerus in the dependent position. In 1987 Laumann provided further evidence that the scapula was upwardly rotated by about 3 degrees. The majority of the current evidence contradicts Laumann and Bazant findings. The new evidence suggests that the scapula rests in a downwardly rotated position. The mean angle ranges from 4-5 degrees with a raw score range of 22 degrees of downward rotation to 12 degrees of upward rotation. Four to five degrees of downward rotation is currently being accepted as the mean carrying angle but it is obvious from the raw scores range that large variations occur between individuals. This variation in carrying angle measurements maybe partially due to differences in arm position when roentgenograms are taken. An interesting finding found in Laumann’s article was that a weight of 20 kilograms or more was needed to change the resting angle of the scapula.

The scapula’s position in relation to the frontal plane has been a subject of great debate. A majority of
the studies that measured the distance between the resting position of the scapula and the frontal plane found mean angles ranging from 30-45 degrees.\textsuperscript{7,22,27,28} This scapular angle was named the scapular plane. A more indepth analysis of the plane of the scapula will be discussed in the next section. In men the resting position of the scapula forms a 60 degree angle with the clavicle at the acromioclavicular joint, as viewed from the transverse plane.\textsuperscript{29} A study done by Culham and Peat\textsuperscript{22} calculated the clavicle scapular angle in women to be 49 degrees.

Along with its orientation in the scapular plane the scapula has a forward or anterior tilt in relation to the sagittal plane. The three studies reviewed for this paper indicates the inferior angle is positioned posteriorly to the superior angle creating a scapular tilt angle of 12,18, or 30 degrees depending on which study is quoted.\textsuperscript{7,13,30} The scapula’s tilt angle was effected by the slope of the upper thoracic spine. With the increased trunk flexion associated with old age the scapula’s anterior tilt angle increases correspondingly.\textsuperscript{22}

Muscles, fascia, and ligaments provide the physiological structures that maintain the scapula in its resting position. The resting position is not maintained by active muscular effort.\textsuperscript{7} All the muscles that insert onto the scapula play a role in maintaining the postural position of the scapula.
The levator scapula and the upper trapezius are the two muscles that are mostly responsible for suspension of the scapula on the thoracic wall. The levator scapula has a larger cross sectional area than the upper trapezius. This larger cross sectional area allows the levator to be a stronger suspensory mechanism. Even though the levator scapula has a larger cross sectional mass the upper trapezius has a larger insertion on the spine of the scapula and the clavicle. The large insertion area and greater lever arm advantage makes up for the decreased muscle mass of the upper trapezius.

The suspensory function of the upper trapezius is further supported by enzymatic and histochemical studies. The study found that the trapezius was divided into three sections descending, transverse, and ascending with a further differentiation of the descending portion into an upper and lower section. The lower section of the descending as well as the transverse and ascending trapezius showed a predominance of Type I fibers while the superior portion of the descending fibers showed a predominance of Type II fibers. Based on previous studies which compared fiber type with specific functional demands the findings showed when a predominance of Type I fibers were found the muscle’s main role was a postural one. The Type II muscle fibers were associated with phasic activity. This study
supports the concept that the majority of the trapezius functions as a postural muscle.

EMG studies also confirm that there is little muscle activity in the levator scapula and upper trapezius during stationary standing. It was once thought that the upper slip of the serratus anterior and the rhomboids played a role in suspension of the scapula because of their oblique vertical orientation. Further investigation showed that the vertical orientation of the fibers was not significant enough to act in a suspensory role for the scapula.

The true role of the rhomboids, serratus anterior, and middle trapezius is to control the abducted or adducted motion of the resting position of the scapula. These muscles as well as the levator and trapezius achieve their goal through resting muscle tone or passive elastic restraint. When the trunk changes from an erect to a flexed position the middle trapezius and rhomboids passive role changes to an active one. When the trunk is flexed the arms fall forward and their intrinsic weight pulls the scapula into an abducted position. This causes the middle trapezius, rhomboids, and levator scapula to be put on stretch. Thus they fire to actively adduct the scapula. This flexed trunk posture is a probable cause of increased neck and thoracic muscle pain associated with the elderly population.

Selective paralysis of muscles helps us understand
their postural roles. When the trapezius is paralysed the scapula becomes more abducted and orients itself in a parasagittal plane. Paralysis of the serratus anterior causes medial migration of the scapula with a more parallel orientation to the frontal plane.

The fascia plays a very important role in the postural positioning of the scapula. The intricate infrastructural relationship between the various layers of fascia and muscle fibers makes it a very plausible theory that it is the fascia that provides the passive elastic restraint or suspension associated with muscles. There is a deep fascia that runs from the head down to the clavicle and spine of the scapula which encloses the trapezius. Some clinicians believe that chronic forward shoulder positions stretch this fascia while at the same time allowing contractions to develop in the anterior pectoral fascia. Thus the result would be chronic rounded shoulders with weakness of the medial inserting scapular muscles. This concept of over stretched muscles being weak will be discussed in the next paragraph.

The effects of aging and abnormal posture on the resting position of the scapula is speculative. A study by Culham and Peat, addressed this issue. Their findings indicated several things. First, in the elderly and osteoporotic population where the flexed trunk posture is common the scapula, clavicle, and humerus are retracted as a
compensatory mechanism to maintain balance. Second, when the thoracic spine becomes more kyphotic the angle formed between the clavicle and the scapula at the acromioclavicular joint becomes more obtuse. The axioscapular distance did not increase thus refuting the theory that kyphosis causes stretching and weakening of the medially inserting scapular muscles. No downward rotation of the scapula was correlated with increased kyphosis. Cailliet\textsuperscript{33} had postulated that with the increase in the anterior-posterior dimensions of the chest the scapula would lateralize and downwardly rotate. Third, there was an increase in the forward or anterior tilt angle of the scapula with age. This was due to the flexed posture of the upper thoracic cage found in the elderly.\textsuperscript{22}

Florence Kendall and Suzan Sahrmann have put forward the theory that overstretched muscles are weak and thus they have an adverse effect on postural alignment. In a study done by DiVeto, Walker, and Shibinski\textsuperscript{21} they set out to prove that there was no relation between the scapula’s resting position and muscle weakness. They cited the statement in the text book of Kisner & Colby\textsuperscript{34} that "weakness of the scapular retractors, such as the upper trapezius, lower trapezius, and rhomboid muscles causes increased scapular abduction or a forward posture, during relaxed standing" as their alternative hypothesis. The studies findings showed that there was no relationship
between the strength of the scapular retractors and the resting position of the scapula. This research brings into doubt the clinical practice of recommending strengthening of scapular stabilizers as a means to effect forward shoulder posture.

SCAPULAR PLANE ANALYSIS

The first chapter on phylogenetic development reviewed the evolutionary explanation for how the scapula arrived at its current resting orientation. As the anterior posterior distance of the thoracic cage decreased the scapula moved from a sagittal plane position to its current more medial position. This medial migration places the scapula closer to the frontal plane than to the sagittal plane. Early shoulder researchers such as Fick used their observational skills to describe the scapula’s parasagittal resting position as early as the early 1900’s. Future researchers used roentgengrams to quantify the angle in which the scapula was positioned. A majority of the researchers place the plane of the scapula some where between 30-45 degrees to the frontal plane. A more anatomical correct definition of the plane of the scapula is the plane drawn at a right angle to the glenoid cavity through its greatest vertical diameter.

Saha noted that the plane of the scapula is not a static position which is measured while the scapula is in
the resting or postural position. The plane of the scapula is always determined by the right angle to the glenoid cavity. During shoulder elevation the clavicle protracts the scapula thus changing the scapular plane as the scapula moves around the thoracic wall. This concept that the scapular plane is dynamic provides support for the use of diagonal or PNF patterns instead of pure planar motions in shoulder rehabilitation.

Humans rarely perform arm movements in pure planar movements such as abduction in the frontal plane or flexion in the sagittal plane. Most shoulder motions are performed in diagonal or scapular planes. The historical debate has been over the proper nomenclature used to describe arm motions as put forward by anatomist and clinicians. The accepted practice has been to describe the movement in terms of how motion at a joint changed the relative angle between the two connected bones. For example elbow flexion describes the decreasing angle between the humerus and radial ulnar complex. In the shoulder this concept has not been used. Anatomist have labeled shoulder movements as they pertain to the humeral position related to the midline of the body, not in relation to the scapula. Because the scapula lies in a plane 30-45 degrees to the frontal plane abduction should be described in this plane not in the pure frontal plane. This is further complicated by the fact that the plane of the scapula is not stationary.
The specific plane used to raise the arm is irrelevant due to the fact that at the end range or the fully elevated position the humerus and scapula are always in the scapular plane. Further support for the use of the scapular plane as the reference plane comes from what Fick called the "Dead Meridian Plane" and Nobuhara called the "zero position". These two terms describe the relationship between the humerus and the scapula. The humeral head is retroverted about 30 degrees. This 30 degrees of retroversion corresponds to the scapular plane angle of 30 degrees. This straight alignment provides several benefits to arm elevation in the scapular plane. First, the inferior capsule is not twisted as is found in pure planar elevation. Second, the deltoid and supraspinatus are in optimum alignment on the length tension curve to produce the force couple needed at the glenohumeral joint. Third, the center of the humeral head approximates very closely the center of the glenoid fossa during elevation in the scapular plane. This provides for a stable nonpathological glenohumeral joint. Finally, because of the scapular plane and the 30 degrees of humeral retroversion the natural swing pattern of the humerus is diagonally across the body. This pattern becomes obvious when observing the arm swing pattern during ambulation. The across the body arm pattern corresponds to the D1 flexion
and extension pattern in PNF. Again this is further evidence to supports the use of diagonal or PNF patterns in shoulder rehabilitation programs.

SCAPULAR BIOMECHANICS

Describing scapular biomechanics is very complex. The complexity of quantifying scapular motion is due to several factors. First, when any type of research is done standards are needed to create uniformity in the scientific literature. In the case of the scapula, uniformed standards have not been used. For example earlier researchers like Inman and Saha measured scapular motion in frontal and sagittal planes while more current researchers have used the scapular plane. This lack of uniformity has negated accurate comparison between different studies. Second, in the different studies the arm elevation increments used to measure scapulohumeral rhythm vary from every 15 degrees up to 45 degrees. Third, some of the studies used all men or all women while others studies had pathological and normal shoulders mixed in the same sample population. Combining male, female, pathological, and normal shoulders acts as a confounding factor of the data because of the known anatomical and biomechanical differences between males and females.

The final factor concerns how measurements were taken and what components where measured. It stands to reason
that since the original work done by Inman the technology used to measure scapular motion has improved significantly. The current research with its advanced technology has both provided evidence to support some of the original findings like a 2:1 ratio for humeralscapulo rhythm for the total arm elevation and specific muscle force couples, both of which were identified in Inmans original work. The advanced measurement techniques have also brought into doubt some of the specific details postulated in the original studies. The fact is that none of the original or subsequent studies are totally comprehensive in their analysis regarding scapular motion and the forces that generate those motions. Many of the studies measured just scapular motion while others only measured EMG activity of the muscles that control scapular movements. The studies where both scapular movement and EMG activity were monitored only a few primary muscles were monitored. Even with all the negative factors previously mentioned the research as a whole has provided us with a good biomechanical understanding and the awareness that the more we learn about the scapula the more complex it becomes.

The scapula is one component in the shoulder complex. The structure and function of the other components such as the sternoclavicular and acromioclavicular joints will have an impact on scapular motion. In the following explanation of scapular motion the description will apply to scapular
motion in the scapular plane. As mentioned before the scapular plane is more functional and thus is more relevant to clinical knowledge.²⁵

The best way to measure scapular motion is to analyze its instantaneous center of rotation (ICR). Poppen and Walker²⁴ first used this type of analysis in 1976. Measurement of the ICR allows the researcher to monitor a dynamic multiplanar motion such as the motion of the scapula. By using the ICR to analyze scapular movement we can divide the elevation of the arm in the scapular plane into three stages. The first stage corresponds to 0-80 degrees of elevation. The second stage corresponds to 80-140 degrees. The last stage is from 140 degrees on to full elevation.³⁶

The first stage can be divided into two parts. The ratio between the two parts varies between individual. The initial phase is called the setting phase. Laumann⁷ described the setting phase as the time when the scapula is moving from its resting position to its designated plane of motion. During the setting phase their is no consistent ICR.²²,²⁹,³⁶,³⁸ The scapula demonstrates transatory movements which can vary in different directions: superior, inferior, lateral, or medial.⁴,³⁹ Of the first 80 degrees of arm elevation the setting phase varies from 0-30 degrees to 0-60 degrees depending on the study.⁴,¹⁵,¹⁹,²⁴,²⁶,³⁶

When the scapula has found its balance point, or in
other words the setting phase is over, the ICR assumes a more consistent position on the scapula. This ICR point for the first stage is located near the medial base of the spine of the scapula.\textsuperscript{22,29,36} A posterior-anterior line drawn through the base of the scapular spine would bisect the sternoclavicular joint.\textsuperscript{22,36} The aforementioned imaginary sagittal axis would be the hinge of an imaginary stirrup formed by the clavicle and scapula. Rotation of the scapula around this axis would occur during the first stage.

The second stage of scapular motion overlaps with the end of the first stage around 80 degrees of arm elevation. The second stage corresponds to the migration of the ICR from the medial base of the scapular spine laterally to the acromioclavicular joint. At a point between 60-90 degrees of arm elevation the ICR begins to move laterally on the scapular spine. Motion begins to occur around the sagittal axis that connects the SC joint and the medial base of the scapular spine. There is a linear relation between clavicular elevation and scapular rotation.\textsuperscript{36,38,39} The clavicle is elevated about 30 degrees before the costoclavicular ligaments prevent further elevation. At the same time the scapula is rotating upward about 30 degrees, thus causing the inferior angle to abduct. The second stage provides the most scapular rotation found in any of the three stages. During scapular rotation the ICR migrates laterally until the ICR reaches the AC joint which
corresponds to the point in which the clavicle has reached maximum elevation. The point in which the ICR is located at the AC joint is somewhere between 120-150 degrees of arm elevation.\textsuperscript{36}

The third stage is from 150 degrees to full arm elevation. As described in the second stage the ICR of the scapula is located at the AC joint when the third stage begins. Due to the fact that the clavicle can no longer elevate, the scapula must find a new point of rotation which is provided by the acromion's hinged attachment to the distal clavicle.

The last four paragraphs have described the motion of the scapula during scapular plane elevation as viewed from the frontal plane. The scapula also moves within the transverse and sagittal planes. Viewing scapular motion from a position above the shoulder or in other terms viewing the scapula in the transverse plane provides another clue to the scapula’s multiplanar motion. The scapula follows the thoracic cage around the body in scapular plane elevation. A vertical axis through the SC joint causes the clavicle to act as a strut. This strut allows 15 degrees of protraction of the clavicle and thus the scapula is protracted because of the attachment via the AC joint.\textsuperscript{30}

At the same time the clavicle is undergoing protraction via its vertical axis through the SC joint there is another vertical axis that runs through the AC joint. This vertical
axis allows the vertebral border of the scapula to move away from the posterior thoracic wall ie. scapular winging. The vertical axises work in synch to produce both scapular protraction and scapular winging at the same time. These axis allow the scapula to move from its resting position in a semi-frontal plane to a parasagittal plane with arm elevation in the scapular plane.

The most clinically relevant scapular motion occurs in the sagittal plane. The scapular motion that occurs in the sagittal plane has several different names; scapular twisting, external rotation of the scapula, counterclockwise rotation of the scapula, or scapular torsion. The frontal axis for this rotation runs in a lateral to medial direction through the center of the glenoid fossa. The twisting motion around the frontal axis is described as the superior angle moving away from the thoracic wall while the inferior angle moves toward the chest wall. In its resting position the scapula forms a 20 degree angle with the frontal plane this is called the anterior tilt of the scapula. While the humerus is elevated in the scapular plane the scapula begins to rotate counterclockwise around this frontal axis. The anterior tilt gradually is reduced to 0 degrees by the time the humerus has reached 90 degrees of elevation. During the last 90 degrees of humeral elevation the scapula continues to rotate counterclockwise so that the scapula is now in 20 degrees of posterior tilt.
The total amount of scapular twisting is 40 degrees from its resting position to maximum posterior tilt. The clinical relevance of scapular twisting is that in relation to each other the humerus does vary little rotation. The two bones rotate in unison. By having the scapula rotate the acromion is rotated in a manner that allows the greater tubercle of the humeral head to pass underneath without causing impingement. Therefore with full internal rotation of the humerus the arm can be elevated substantially more in the scapular plane than in the frontal plane.

**SCAPULO THORACIC MUSCULAR FORCE COUPLES**

Scapular muscles produce two types of movements, translatory and rotatory. Rotatory movements of the scapula consist of upward and downward rotation, scapular winging around the AC joint, and scapular twisting around the frontal axis. The muscles that attach to the scapula use the physics principle of force couples to produce the rotatory movements. Translatory movements of the scapula consist of elevation, depression, protraction, and retraction. The translatory movements of the scapula are controlled by linear forces created by agonist and antagonist muscles. Researchers have used EMG studies and force vector analysis to determine which muscles are involved in specific scapular motions.

First, rotatory movements of the scapula will be
described. The two rotatory movements most associated with the scapula are upward and downward rotation. The best way to sequentially explain the muscle forces that control upward rotation is to divide arm elevation into three stages. These three stages correspond to the previously explained stages of ICR movements in the scapula.

The first stage is defined as the angular distance between 0-80 degrees of humeral elevation in the scapular plane. During this stage three muscles produce the force couple that upwardly rotates the scapula. The upper fibers of the trapezius and the levator scapula form the superior portion of the force couple. The lower fibers of the serratus anterior which attach to the inferior angle form the inferior portion. Force vector analysis shows that the lower fibers of the serratus anterior have the longest lever arm of all three muscles thus it has a mechanical advantage in the force couple. During the first stage the ICR is located near the medial root of the scapular spine. The location of the ICR is a function of the different attachment sites and lines of pull produced by the three primary muscles. EMG studies provide quantitative data that shows a correlation between a gradual increase in EMG activity of the upper trapezius, levator scapula, and lower serratus anterior during scapular upward rotation.

The second stage is defined as the interval between 80-140 degrees of humeral elevation. At a point roughly
between 60-90 degrees of elevation the ICR begins to move toward the AC joint. Throughout the second stage the ICR moves laterally until it arrives at the AC joint at a point somewhere between 120-150 degrees of humeral elevation. The lateral migration of the ICR signals the fact that the force couples producing the rotation of the scapula are changing. At 90 degrees of arm elevation the force lever arms of the levator scapula and upper trapezius begin to gradually lose their biomechanical advantage.\textsuperscript{36} At this point the force lever arm of the lower trapezius fibers are at their optimum.\textsuperscript{36} From 90 degrees on, the lower fibers of the trapezius and the lower fibers of the serratus anterior play a larger role in the scapula’s upward rotation. This force vector analysis of the scapula is further supported by EMG studies.\textsuperscript{36} Throughout the first stage there is a gradual increase in EMG activity of the levator scapula, upper trapezius, and serratus anterior; but at about 90 degrees of humeral elevation those muscles show a "plateauing effect". While at the same time (90 degrees) the lower trapezius shows a large jump in EMG activity. The plateau phase of the upper trapezius and lower fibers of the serratus anterior can be explained by the fact that as these muscle force lever arms are reduced. The large increase in muscle activity of the lower trapezius at 90 degrees of humeral elevation makes up for the lose of the biomechanical advantage of the two plateaued muscles. Near the end of the
second stage or roughly 140 degrees of humeral elevation a majority of scapular rotation has occurred.

The third stage of scapular plane elevation is defined as the interval from 140 degrees to terminal elevation. At the end of the second stage the clavicle has reached maximum elevation and the ICR has moved to its final position at the AC joint. The clavicles primary elevator is the upper trapezius. So by 140 of elevation the trapezius force lever arm has been greatly reduced due to the fact that it has achieved its primary goal of elevating the clavicle. From this point on the upper trapezius’s role is mainly one of shoulder girdle support. The lower trapezius and the lower serratus anterior are now the primary upward rotators of the scapula during the last 40 degrees of humeral elevation.

Gravity plays a major role in downward rotation of the scapula. During passive adduction of the humerus, gravity is the agonist while the antagonist is the eccentric action of the muscles that upwardly rotate the scapula. During active or resisted downward rotation several muscles are involved. The middle trapezius, rhomboids, levator scapula, pectoralis minor, and the upper slip of the serratus anterior are all well suited for downward rotation. The latissimus dorsi and the lower fibers of the pectoralis major play a secondary role via their ability to actively
adduct the humerus thus causing the scapula to rotate downward.\textsuperscript{38,39}

Scapular winging through its vertical axis at the AC joint is considered a rotatory movement. The scapula can wing up to a maximum of 50 degrees.\textsuperscript{30} Scapular winging is a product of two forces; skeletal structure and anterior muscle forces. When the scapula is protracted around the thoracic wall the scapula goes from a parafrontal plane to a parsagittal plane. The shape of the skeletal cage determines the scapula’s path and thus to a small degree scapular winging. The muscles that assist with scapular protraction are the pectoralis minor and major. With the forces generated by these two muscles around a vertical axis at the AC joint the vertebral border of the scapula moves posteriorly away from the thoracic cage as well as protracts.\textsuperscript{36} The middle sections of the serratus anterior, trapezius, and rhomboids act to counter act the scapular winging motion.

Scapular twisting is also considered a rotatory motion around a frontal axis through the center of the glenoid fossa. Scapular twisting like scapular winging is controlled by two factors, rib cage shape and muscle forces. To understand the skeletal shape factor the scapular twisting motion must be viewed in the context of all scapular motion. As the scapula rotates around a dynamical ICR that is migrating laterally the inferior angle is being
abducted or moved laterally. With the abduction of the inferior angle it clears the inferior angle from the anterior barrier created by the thoracic cage. This allows the inferior angle to move anteriorly and create the counterclockwise rotation around the frontal axis. The primary muscle force that rotates the inferior angle is the lower fibers of the serratus anterior. The upper trapezius, levator scapula, and rhomboids also play an important role. Scapular protraction requires these muscles to relax thus enabling the superior angle of the scapula to move slightly posterior in a counterclockwise rotation. Two other muscles are involved in the active return of the scapula from its posteriorly tilted position to its anteriorly tilted resting position. These two muscles are the pectoralis minor and the coracobrachialis. Their insertion on the coracoid process of the scapula allows them to pull the superior section of the scapula closer to the thoracic cage, thus creating the 20 degrees of anterior tilt found in the resting position of the scapula.

Translatory movements of the scapula are relatively easy to describe in terms of the muscle forces that produce them. The scapula can be elevated a maximum of 2-3 cm. The primary movers are the upper trapezius, levator scapula, rhomboids, and upper slip of the serratus anterior. The primary movers involved in scapula depression are the lower trapezius, lower serratus anterior, pectoralis minor,
pectoralis major, and latissimus dorsi. Maximum scapular protraction is 2-4 cm. The primary movers are the pectoralis minor, pectoralis major, and serratus anterior. The last translatory movement of the scapula is retraction. Maximum scapular retraction is 2-4 cm. The primary movers are the middle and lower trapezius and rhomboids. The rhomboids play a very important function in overhead activities such as pitching. EMG studies have shown that the rhomboids provide eccentric control for scapular protraction and upward rotation during the acceleration phase of pitching. This eccentric control allows for smooth controlled motion. The rhomboids also act as an eccentric break during the follow through phase of pitching.

A majority of the information provided in this paper concerning muscle forces is focused on concentric contractions. Eccentric contractions play a very important role in scapular motion and even a more important role in glenohumeral motion. Eccentric control is needed to provided synchronized and fluid scapular motion. Eccentric contractions also balance out or negate unwanted scapular motions created by concentric primary movers. A detailed description of the eccentric contributions to scapular motion is beyond the scope of this paper.
SCAPULOHUMERAL RHYTHM

The term scaplohumeral rhythm describes the complex interaction between the scapula and humerus during arm elevation. Maximum humeral elevation varies greatly between individuals. Different studies show that maximum humeral elevation ranges between 168-180 degrees.\textsuperscript{4,19,26,36} Inman et al.\textsuperscript{4} stated that the scapula contributes 60 degrees while the humerus contributes 120 degrees for a total of 180 degrees of humeral elevation. The amount of motion at the glenohumeral versus the scapulothoracic joints during each of the three phases of arm elevation is controversial. The GH:ST ratio is the term used to describe the amount of relative contribution by each joint during elevation.

Inman et al.\textsuperscript{4} original work stated that after the setting phase (0-30 degrees) the GH:ST ratio was 2:1. In most of the studies concerning GH:ST ratios the setting phase is not calculated in the overall ratio because of its highly inconsistent measurements. Later Saha\textsuperscript{36} found the overall GH:ST ratio to range between 2:1 to 3:1. The studies by Inman and Saha measured arm elevation in the frontal plane. The rest of the studies which will be discussed in this paper measured humeralscapulo ratios in the scapular plane.

Poppen and Walker\textsuperscript{24} found the overall GH:ST ratio to be 1.25:1 in the scapular plane. In 1976 Freedman and Munro\textsuperscript{19} found a slightly larger overall ratio of 1.5:1.0 and Doody
and associates\textsuperscript{26} found an even larger ratio of 1.74:1.0. None of the scapular plane measurements of GH:ST ratios ever came close to the 2:1 or 3:1 ratios that Inman and Saha found. Doody et al\textsuperscript{26} and Freedman and Munro\textsuperscript{19} GH:ST ratios for the three stages of scapular plane elevation showed a common trend. Both studies showed that the glenohumeral joint was the largest contributor during the first phase 0-30 degrees (7.29:1). The scapulothoracic joint increased its role during the second phase 90-150 degrees (.787:1). During the last stage 150-180 degrees the glenohumeral joint again became the main contributor. Comparing all the studies on GH:ST ratios the amount of variation found was significant. Factors causing the variation were sex, size of increments of arm elevation between measurements, measurement in different planes, and individual variations such as arm weight and muscular strength.

In summary of this chapter a couple of points should be remembered. First, when a therapist access the resting position of the scapula or its movement patterns in the scapular plane he or she needs to realize that a great amount of variation occurs between individuals. Second, the forces that create scapular movement are very complex. The multifunctional roles of scapular muscles and their dynamic interaction creates a structure that is hard to diagnosis specific mechanical dysfunctions.
CHAPTER IV
FUTURE RESEARCH NEEDS

This paper has reviewed the scapula from its evolutionary development to the current biomechanical concepts of its's involvement in upper extremity mobility. As one reviews the literature concerning the scapula it becomes obvious that there are a series of steps that need to be taken to increase the scientific communities knowledge of the role the scapula plays in normal and pathological shoulder motion.

Standardization of the descriptors and criteria researchers use to analyze scapular and shoulder motion is the most fundamental change needed. The first criteria that should be standardized is plane of motion (scapular, frontal, sagittal) to be used as the gold standard for research. The second criteria that needs standardization is angular intervals used to divide shoulder elevation into its component parts. In the past the angular intervals varied from 15 degrees to 60 degrees. This large variation creates inconsistencies in the data produced by these studies. Third, researchers need to implement stringent controls on demographic variables. Variables such as sex, age, and
shoulder pathologies act as confounding factors in experimental studies concerning shoulder and scapular function. In the current and past literature the need for statistically significant numbers of subjects has lead to the inclusion of subjects whose demographic data confounds experimental conclusions. The lack of standardization in the current body of literature has negated the comparison of the large volume of studies concerning scapular and shoulder function.

Along with the standardization of future research there is a clear need for a comprehensive multifaceted shoulder study. To date no shoulder study has used a statistically significant number of subjects and measured all the biomechanical and kinesiological factors involved in shoulder and scapular motion. Most of the current theories regarding scapular and shoulder motion have been developed from the synthesis of information ascertained from various narrowly defined studies. For example one study regarding EMG activity of a few scapular muscles is used in conjunction with a study that measured scapular motion radiographically to develop a hypothesis for scapular biomechanics. There is a need for research that measures all the shoulder variables in a large homogeneous group. The homogeneity of the group will be determined by demographic factors such as age, sex, and pathology vs. nonpathological. The shoulder variables that need to be
measured are scapulohumeral rhythm, muscular strength, agonist and antagonist strength ratios, EMG activity, anatomical variation, and specific diagnosis of structures involved in pathology classification. Again all the criteria used to measure these variables needs to be standardized.

The physical therapy profession stands to benefit greatly from indepth biomechanical studies regarding the scapula. This paper has been designed to give the clinician a comprehensive overview of the scapula and its function in the shoulder complex. With this knowledge the therapist should be able to critically review current and future rehabilitation protocols.
REFERENCE


