

Kinesiology of the Shoulder Complex

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The purpose of this article is to present a kinesiological analysis of motion of the shoulder complex. The literature of the shoulder complex kinesiology is reviewed and is presented as a cohesive whole. Basic information regarding structural components of the shoulder complex is presented in table form for easy accessibility.

Terminology is defined. The coordinated movement of the three bones of the shoulder complex is described and their interdependence is emphasized. The clinical importance of this interdependence is stressed. Finally, basic biomechanical and kinesiological information is used to analyze motion of the shoulder complex as a whole. Combined muscle actions are described throughout the range of motion for four representative movements.

The upper extremity engages in diverse functions through a wide range of motion. The shoulder complex has multiple articulations, and upper extremity movement requires movement of all components of the shoulder complex. The combination of muscles acting during motion is dependent on biomechanical factors related to muscle size and length, joint angle, force of movement, gravity, etc. For these reasons analysis of shoulder movement is difficult. It is necessary to analyze both static and dynamic factors in posture and movement. In this paper, we summarize the structural and biomechanical information necessary for analysis of movement of the shoulder complex. We then review the literature describing shoulder complex movement and analyzing specific muscle functions. Finally, we describe four representative motions as examples of use of structural, biomechanical, and kinesiological information for the analysis of movement.

COMPONENTS OF THE SHOULDER COMPLEX

The bones of the shoulder complex are the humerus, scapula, and clavicle. The shoulder complex has three articulations: glenohumeral,

acromioclavicular, and sternoclavicular. In addition, there is one "functional" articulation between the scapula and the thorax. The sternoclavicular joint is unique because it represents the only bony connection between the entire shoulder complex and the thorax, and hence with the rest of the body. This implies that the shoulder complex depends on nonbony connections to maintain its integrity with the body. The so-called scapulothoracic joint, comprised of muscular attachments of scapula to thorax, is of major importance in maintenance of that integrity.

The shape of articulating surfaces, ligamentous structures, and joint capsules are critical structural factors determining degrees of freedom, stability, and ultimate range of movement that can occur between two articulating surfaces. These factors, in combination with muscle length and strength, play a major role in determining individual differences in flexibility and mobility, predisposition to injury, and the distinction between normal and pathological movement. The clinician who is analyzing movement needs a good knowledge of these joint structures. The structural components of the shoulder complex have been well described.^{5,6,14,22} Some of the relevant information is summarized for easy accessibility (Tables 1 and 2). Arthrokinematics is important but is not discussed in this article.

Structure dictates function. The architecture of bony surfaces that articulate determines the degrees of freedom of available movement and sets outside limits to the available range of motion.²² Ligaments, joint capsular structures, and muscle

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TABLE 1
*Ligaments of the shoulder complex**

1. Sternoclavicular joint
 - a. Interclavicular ligament
 - Connects two clavicles
 - Checks downward, lateral, and upward motion of the clavicle
 - Supports weight of upper extremity
 - b. Costoclavicular ligament
 - Connects clavicle to first rib
 - Checks clavicular elevation and lateral movement
 - Checks anterior and posterior movement of the clavicle in the horizontal plane
 - Supports weight of upper extremity
 - c. Sternoclavicular ligament
 - Anterior and posterior portions
 - Connects clavicle to sternum
 - Prevents anterior and posterior dislocation of the clavicle
 - Supports weight of upper extremity
2. Glenohumeral joint
 - a. Coracohumeral ligament
 - Connects humerus to coracoid process of scapula
 - Provides tension anteriorly with extension
 - Provides tension posteriorly with flexion
 - Checks upward displacement of humeral head
 - Protects underlying structures
 - Checks external rotation of the humerus
 - Supports weight of upper extremity
 - b. Glenohumeral ligament
 - Connects humerus to glenoid fossa of scapula
 - Consists of three bands: superior, middle, and inferior
 - All three bands become taut with external rotation
 - Middle and inferior bands become taut with abduction
 - Prevents anterior dislocation of humerus
 - c. Transverse ligament
 - Across the bicipital groove of humerus
 - Maintains biceps tendons in bicipital groove
3. Acromioclavicular joint
 - a. Acromioclavicular ligament
 - From the acromion to the clavicle
 - Superior and inferior portions
 - Prevents clavicle overriding acromion
 - Prevents separation of the scapula from the clavicle
 - b. Coracoacromial ligament
 - From coracoid process to acromion
 - Forms the supraspinatus sulcus
 - c. Coracoclavicular ligament
 - From the coracoid process to the clavicle
 - Two portions: trapezoid and conoid
 - Prevents upward dislocation of clavicle from scapula
 - Prevents downward dislocation of scapula from clavicle
 - Maintains scapula and clavicle in constant relationship
 - Prevents anterior and posterior movement of scapula

* Material for this table was compiled from a number of sources.^{1,2,4,9,14,18}

length may further limit the available range. The relative degrees of stability and mobility are a reflection of the composite of these factors. The theory of evolution of the shoulder complex suggests that the functional changes occurred during the transition from quadruped to plantigrade. This transition necessitated alteration of the limb from one used primarily for stability in weightbearing to one used primarily as a mobile structure.

The major muscles producing motion within the shoulder complex have been well described.^{13,15} These muscles can be divided into three separate groups: muscles that originate on the shoulder complex and insert on the humerus or elbow, muscles that originate on the trunk and insert on the shoulder complex, and muscles that originate on the trunk and insert on the humerus (Tables 3 and 4).^{11,15} The shoulder complex functions as a kinematic chain. Although it is comprised of three distinct segments, movement of any one of those segments may produce movement in other segments. For example, movement of the humerus through action of the latissimus dorsi or pectoralis major (both of which originate on the trunk) will produce movement of the scapula and clavicle as well. Conversely, pathological shortening of latissimus dorsi or pectoralis major would limit available range of motion of the scapula although there is no direct connection to the scapula. One of the most important aspects of the shoulder complex is the intricate and delicately balanced interplay of all components of the kinematic chain.

Muscles almost always act in combinations to produce motion. In addition to those muscles that are primarily responsible for a given motion, there are muscles that play secondary and synergistic roles, or that provide stability elsewhere in the body. A prerequisite for normal movement is for all relevant muscles to act synchronously and appropriately. Different terminologies have been used to describe the various roles that muscles play. In this paper, we will use the following definitions. A prime mover is the main force that produces motion at a joint.^{15,18} If the prime mover is a muscle, it is also called an agonist. The term agonist may also be used to describe muscles primarily responsible for maintaining a position.¹⁵ A secondary mover, or assistant, is a muscle that produces only some of the combined actions of a prime mover or that is recruited only if the action becomes forceful.²³ Synergists are muscles that contract at the same time as the prime mover to produce a desired motion.¹⁸ There are two distinct

TABLE 2
*The shoulder complex—range and axis of motion**

Joint and motion	Range	Axis of motion
Sternoclavicular		
1. Rotation (counter-clockwise)	0–50°	Longitudinal axis of clavicle
2. a. Elevation	0–30°	Oblique through costoclavicular ligament
b. Depression	0–5°	
3. a. Protraction	0–15°	Vertical through costoclavicular ligament
b. Retraction	0–15°	
Glenohumeral		
1. a. Flexion	0–180°	Coronal through glenohumeral joint
b. Hyperextension	0–55°	
2. a. Abduction	0–180°	Sagittal through glenohumeral joint
b. Horizontal adduction	0–45°	
		Vertical through glenohumeral joint
3. a. Internal rotation	0–90°	Vertical axis through shaft of humerus
b. External rotation	0–90°	
Acromioclavicular		
1. Winging of scapula	0–50°	Vertical axis through AC joint
2. Abduction of scapula	0–30°	Anterior-posterior axis
3. Inferior angle of scapula tilts away from chest wall	0–30°	Coronal axis
Scapulothoracic		
1. Upward rotation†	0–60°	From 0–30° near vertebral border on spine of scapula From 30–60° near acromial end of spine of scapula
2. a. Elevation	Translatory	No axis
b. Depression	Translatory	No axis
3. a. Protraction	Translatory	No axis
b. Retraction	Translatory	No axis

* Material for this table was compiled from a number of references.^{1,2,4,9,14–18,21} When conflicting information occurred, the most frequently cited numbers were used in this table.

† See Figure 2.

ways in which synergists can assist: helping synergists are pairs of muscles that have an action in common and an opposite action; they act together to produce the desired motion while the undesired motions cancel each other out.²⁰ In contrast, a neutralizer is a synergist that acts indirectly to assist in a movement by canceling out undesired actions caused by the agonist.^{18,20} Frequently, muscles from many or all categories are required to produce a desired motion.¹⁸ The

antagonists are muscles having an action opposite to the desired motion. Finally, stabilizers are forces that prevent unwanted motion at joints other than those joints where the prime mover exerts its action. For motion to occur normally, the relevant antagonists must appropriately lengthen and stabilizers must act coordinately to provide a stable base throughout the remainder of the body. Analysis of movement requires knowledge and accurate assessment of each of

TABLE 3
Muscle actions at the shoulder complex

Muscle	Action													
	Humerus							Scapula						
	Flexion	Extension	Internal rotation	External rotation	Abduction	Adduction	Horizontal adduction	Elevation	Depression	Downward rotation	Upward rotation	Protraction	Retraction	Anterior tilt
Biceps brachii—short head	•													
Biceps brachii—long head*	•				•									
Triceps brachii—long head		•				•								
Supraspinatus					•									
Deltoid														
Anterior	•		•											
Middle					•									
Posterior†		•		•		•								
Coracobrachialis	•					•								•
Latissimus dorsi		•	•			•				•				
Pectoralis major			•			•						•		
Upper fibers	•						•							
Lower fibers		•				•	•							
Subscapularis			•											
Teres major‡		•	•		•	•								
Infraspinatus				•										
Teres minor				•										
Pectoralis minor									•	•		•		•
Rhomboids								•		•			•	
Levator scapulae								•		•				
Trapezius														
Upper								•			•			
Middle													•	
Lower§									•	•	•		•	
Serratus anterior														
Upper fibers								•			•	•		
Lower fibers									•		•	•		

* Biceps brachii long head may abduct the humerus if the humerus is externally rotated.

† The joint angle will determine whether posterior deltoid can adduct the humerus.

‡ The joint angle will determine whether teres major abducts or adducts the limb.

§ The joint angle will determine whether the lower trapezius upwardly or downwardly rotates the scapula.

the forces that act with the prime movers to produce that movement. Excessive or diminished amount of any given force may alter the entire course of the movement. As the movements of the shoulder complex are analyzed, all participating forces will be considered.

COMBINED MOVEMENTS OF THE SHOULDER COMPLEX

Shoulder complex movements represent carefully orchestrated motion of all of its components. The humerus rotates around the scapula within the glenohumeral joint, the scapula rotates around the clavicle at the acromioclavicular joint, and the clavicle rotates around the sternum at the ster-

noclavicular joint.²² Movement of all of these components must occur for the arm to achieve 180° of humeral elevation. (The term elevation is frequently used in the literature without differentiation between abduction and flexion.)

If the humerus is held in internal rotation, only 60° of elevation is allowed. Furthermore, the humerus must externally rotate during elevation. Otherwise, by 90° the greater tubercle of the humerus will impinge on the coracoacromial arch. In normal movement, only 120° of glenohumeral elevation is permitted within the glenoid fossa. After 120°, motion is blocked by impingement of the surgical neck of the humerus on the acromion of the scapula and on the coracoacromial liga-

TABLE 4
*Muscles of the shoulder complex**

I. From shoulder girdle to humerus, radius, or ulna	
	Deltoid
	Supraspinatus
	Infraspinatus
	Teres minor
	Subscapularis
	Teres major
	Coracobrachialis
	Biceps
	Triceps
II. From trunk to shoulder girdle	
	Serratus anterior
	Trapezius
	Rhomboids
	Pectoralis minor
	Levator scapulae
	Subclavius
III. From trunk to humerus	
	Latissimus dorsi
	Pectoralis major

* From Inman.¹¹

ment. Humeral elevation beyond 120° is accomplished by rotation of the scapula in an upward direction. This rotation positions the glenoid fossa superiorly, passively carrying the humerus through the additional 60° of elevation.

The combined motion of the scapula and humerus is referred to as "scapulohumeral rhythm."⁷ The initial phase of humeral elevation is referred to as the "setting phase." This term is used for the first 30° of abduction and the first 60° of forward flexion.^{10,14} During this early phase, movement of the scapula is not well coordinated with movement of the humerus. The scapula may begin to upwardly rotate. However, it may also oscillate or even downwardly rotate. After the initial 30° of humeral elevation, the scapular motion becomes better coordinated. However, toward the end of the range of humeral elevation the scapula provides more of the motion and the humerus less.¹⁴ Overall, every 1° of scapular rotation is accompanied by 2° of humeral elevation. Scapulohumeral rhythm is said to occur in a 1:2 ratio. If the scapula cannot move, it is possible to elevate the arm passively to 120°. However, it is only possible to abduct the shoulder actively to 90° without scapular movement, because the deltoid becomes actively insufficient, or too short to develop adequate tension.¹⁶

The scapular articulation with the clavicle and the resulting impact of the clavicle on scapular rotation must also be considered. Initially, the scapula rotates upward as the clavicle elevates.¹

From 0–30°, scapulothoracic motion occurs around an axis on the spine of the scapula near its vertebral border.⁸ As the scapula upwardly rotates, it produces elevation of the acromial end of the clavicle. Only 30° of clavicular elevation is permitted, corresponding to 30° of scapular upward rotation (Table 3); further elevation is checked by the costoclavicular and coracoclavicular ligaments (Table 1).^{1,12} Although tension in these two ligaments checks further clavicular elevation, the two ligaments work as a force couple to cause the clavicle to rotate backward around its long axis. Because the clavicle is shaped like a crank-shaft, this rotation produces further elevation of the acromial end of the clavicle (Fig. 1).¹⁰ This, in turn, produces further scapular upward rotation which now occurs around an axis at the acromioclavicular joint (Fig. 2). An additional 30° of scapular upward rotation occurs around this axis for a total of 60° of upward rotation (Fig. 2).

Abbott and Lucas¹ have reviewed the consequences of excision of the clavicle and have pointed out that without clavicular participation the limb can still be actively elevated to 180°. However, strength and stability both are affected. This would be expected as the clavicle provides the only bony attachment of the shoulder complex to the skeleton. Furthermore, loss of the clavicle prevents a shift in the axis of scapular rotation which would in turn affect the participation of the lower trapezius as an upward rotator (see discussion below).

In summary, glenohumeral elevation to 180° must be accompanied by humeral external rotation and by scapular upward rotation. In turn, scapular upward rotation is accompanied first by clavicular elevation and then by clavicular backward rotation.

All components of these motions must occur in

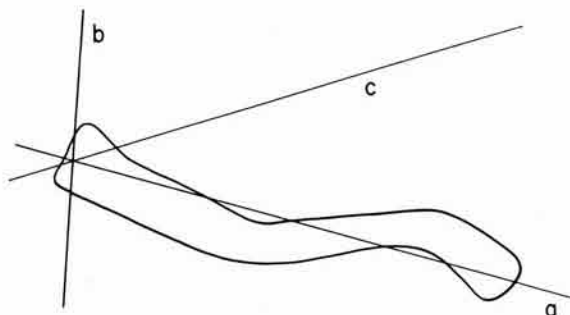


Fig. 1. Axes of motion of the clavicle. a, Longitudinal axis of rotation; b, vertical axis for protraction and retraction; c, horizontal axis for elevation and depression.

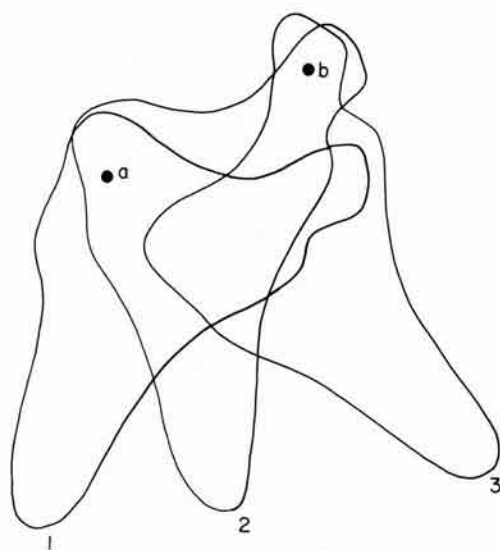


Fig. 2. Posterior view of the scapula during upward rotation. 1, Position at rest; 2, position at 30° rotation; 3, position at 60° (full rotation). a, Axis of motion from 0-30° upward rotation; b, axis of motion from 30-60° upward rotation.

order for humeral elevation to occur smoothly and through full range of motion. These combined motions position the glenoid fossa superiorly to increase limb range of motion and also to prevent active insufficiency of muscles crossing the glenohumeral joint.

Vector representation of muscle action and resolution of force vectors into rotatory and translatory components of force are helpful in describing muscle actions. By this method it is evident that several important force couples act within the shoulder complex. A force couple is defined as two equal forces acting in opposite directions to rotate a part about its axis of motion.¹⁴ Two separate force couples are of particular importance in motion of the shoulder complex. The rotator cuff muscles act in concert with the deltoid to guide the head of the humerus during humeral elevation. The trapezius and serratus anterior act together to produce upward rotation of the scapula.¹¹ Both force couples are depicted by vector representation (Figs. 3 and 4).

During elevation, the humeral head must be approximated in the glenoid fossa as the humerus is rotated. When the humerus is abducted, the rotatory component of the deltoid pulls the humerus outward and the translatory component of the deltoid pulls the humerus upward toward the acromion. The rotatory component of three of the rotator cuff muscles (subscapularis, teres minor, and infraspinatus) is exerted on the proximal side

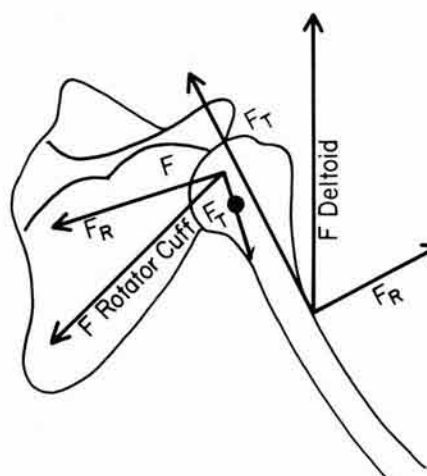


Fig. 3. Force couple of deltoid and rotator cuff muscles. The rotatory forces, acting on opposite sides of the axis of motion, combine to produce upward rotation. The translatory forces cancel each other out. F_R , rotatory force; F_T , translatory force.

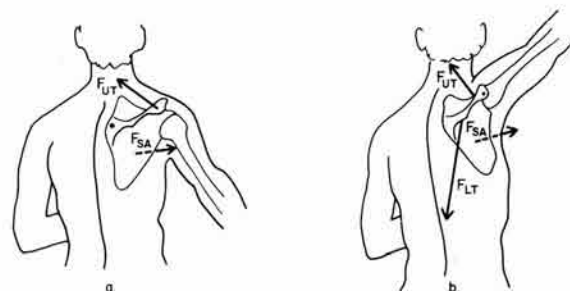


Fig. 4. Force couple of muscles acting at the scapula. F_{UT} , force of upper trapezius; F_{LT} , force of lower trapezius; F_{SA} , force of serratus anterior. a, Axis of scapular rotation from 0-30°; b, axis of scapular rotation from 30-60°.

of the axis of humeral motion, pulling medially. Hence, it too pulls the humerus outward. The translatory component of the force of these rotator cuff muscles pulls the humerus downward (Fig. 3). Even though the two rotatory forces are exerted in opposite directions they combine to move the humerus in the same direction (abduction) because they are applied on opposite sides of the joint axis of motion, forming a force couple. In contrast, the translatory forces of the deltoid and the rotator cuff muscles cancel each other out, stabilizing the head of the humerus within the glenoid fossa.¹¹ If the rotator cuff muscles are not adequately active, the translatory force of the deltoid would presumably pull the humerus upward into the acromion of the scapula. In summary, although the deltoid is considered a prime mover for humeral abduction, it cannot work effectively in the absence of the rotator cuff muscles. In addition to guiding the head of the humerus within the glenoid fossa, infraspinatus and teres

minor also provide the external rotatory force necessary to prevent impingement of the greater tuberosity of the humerus on the coracoacromial arch of the scapula.

Several muscles act together as a force couple that upwardly rotates the scapula. The upper portion of the force couple is comprised of the upper trapezius and upper digitations of serratus anterior. The lower portion of the force couple is comprised of the lower trapezius and lower digitations of serratus anterior.^{2,11} During approximately the first 90° of humeral elevation, the scapula rotates around an axis on the spine of the scapula near the vertebral border (Fig. 2).⁸ Most of the fibers of the lower trapezius exert a downward rotatory force on the scapula, hence they would not be expected to be active in this early stage. Once the humerus reaches 90° of elevation, and the scapula is about 30° upwardly rotated, the axis for scapular rotation shifts to a point on the spine of the scapula near the acromioclavicular joint. Then the lower trapezius would be effective as an upward rotatory force. Most authors do not differentiate between the role of the lower trapezius early in the range of humeral elevation and late in the range. However, Basmajian³ comments that the lower trapezius and lower fibers of the serratus anterior become more active as the scapula progresses through upward rotation. Inman et al.¹¹ suggested that the trapezius, as a whole, plays a predominantly supportive role below 90° and actively participates in upward rotation above 90°. Data of Inman et al. also suggest that the lower trapezius is relatively inactive until 90° of abduction. Furthermore, their data indicate a distinction between the action of the lower trapezius in abduction and in forward flexion. They suggested that the lower trapezius is the more active component of the force couple in abduction but that the muscle must relax to allow forward flexion; the lower fibers of the serratus anterior then become the more active component. Differences in activity of the lower trapezius can be observed clinically by palpation.

ANALYSES OF SPECIFIC MOVEMENTS

In this section we have provided sample analyses of movement of the shoulder complex during selected motions. In these analyses (Tables 5–8) we have used a modification of the format of Riegger and Watkins.²¹ The four activities chosen for analysis are upper extremity abduction to 180°, unresisted return (adduction) of the upper

extremity from 180° to neutral, resisted adduction of the humerus from 180° to neutral, and a sitting push-up. These activities were chosen to illustrate the diverse actions of the shoulder complex. Elevation of the upper extremity against gravity's pull is of major importance during many daily activities including reaching, dressing, eating, throwing, and grooming. The analysis of upper extremity abduction as an open kinematic chain is used to illustrate the intricate interplay of muscles of the shoulder complex during such activities. This analysis also illustrates the shifting axis for scapular rotation and its consequence for action of scapular muscles. Adduction, or the return of the upper extremity to neutral from 180°, is used to illustrate the consequences of movement of the arm in the same direction as the pull of gravity. Under this circumstance, gravity acts as the prime mover and muscles of the shoulder complex act eccentrically to control the fall of the humerus, scapula, and clavicle under the force of gravity. In the third example, forceful shoulder adduction, the humeral adductors and extensors and the scapular downward rotators and depressors act together to bring the upper extremity down against an externally applied upward force. Finally, a sitting push-up is used to illustrate the use of scapular and humeral musculature when the upper extremity is fixed and motion occurs through a closed kinematic chain. The sitting push-up is representative of functional activities such as crutch walking or vaulting.

During unresisted upper extremity abduction the humerus abducts a total of 120° and externally rotates, the scapula simultaneously upwardly rotates 60°, while the clavicle elevates and rotates backward around its long axis (Table 5). The prime movers for the humeral motion include the deltoids and supraspinatus.^{2,3} There has been some suggestion that the supraspinatus acts as an initiator of abduction. However, Basmajian^{2,3} and Inman et al.¹¹ have found that this muscle acts coordinately with the deltoid, playing a quantitative but not a specialized role. While the middle deltoid can work during upper extremity abduction, if the anterior or posterior deltoid participate, they must work together as helping synergists to produce a pure abduction force.¹⁵ The biceps brachii may also contribute to abduction of the upper extremity if the humerus is externally rotated.^{2,3} This is commonly referred to as the biceps mechanism.¹⁶

The muscles discussed above are considered

TABLE 5
Muscle action analysis for upper extremity abduction, 0–180°

Joint and motion	Range	Axis	Prime Movers*	Secondary movers	Helping synergists	Neutralizers	Antagonists
Glenohumeral Abduction	0–120°	Glenohumeral joint	Deltoid Supraspinatus	Biceps brachii (if humerus is externally rotated)	Anterior and posterior deltoid	Infraspinatus Subscapularis Teres minor: neutralize tendency of deltoid to compress humeral head	Latissimus dorsi Pectoralis major Triceps brachii
External rotation	0–70°	Long axis of humerus	Infraspinatus Teres minor Supraspinatus	Posterior deltoid			Anterior deltoid Subscapularis Latissimus dorsi Pectoralis major
Scapular Upward rotation	0–30° 30–60°	Spine of scapula near vertebral border Near acromioclavicular joint	Upper trapezius Upper fibers of serratus anterior Upper and lower trapezius, all of serratus anterior		Upper trapezius and upper fibers Serratus anterior Upper trapezius and upper fibers serratus anterior; upper and lower trapezius		Rhomboids Levator scapulae Rhomboids Levator scapulae
Clavicle Elevation	0–30°	Costoclavicular ligament	Upper trapezius				Subclavius
Backward rotation	0–50°	Long axis of clavicle	Indirect muscle action producing tension on coracoclavicular and costoclavicular ligaments				

Note: Resistance to shoulder abduction is the weight of the upper extremity acting at the center of gravity of the shoulder complex. Resistance to humeral external rotation is the weight of the upper extremity.

* Prime movers act concentrically.

TABLE 6
Muscle action analysis for unresisted upper extremity adduction, 180-0°

Joint and motion	Range	Axis	Primary controllers*	Secondary controllers*	Helping synergists	Neutralizers	Antagonists
Glenohumeral Adduction	120-0°	Glenohumeral joint	Deltoid Supraspinatus	Biceps brachii (if humerus is externally rotated)	Anterior and posterior deltoid	Infraspinatus Subscapularis and teres minor neutralize tendency of deltoid to compress humeral head	Deltoid Subscapularis Infraspinatus Teres minor Upper trapezius Serratus anterior Lower trapezius Infra-spinatus Teres minor
Internal rotation	70-0°	Long axis of humerus	Infraspinatus Teres minor Supraspinatus	Posterior deltoid			
Scapular Downward rotation	60-30°	Near acromioclavicular joint	Upper and lower trapezius Serratus anterior		Upper and lower trapezius Upper trapezius and upper fibers Serratus anterior		Upper trapezius Serratus anterior Lower trapezius
	30-0°	Spine of scapula near vertebral border	Upper trapezius and upper fibers Serratus anterior		Upper trapezius and upper fibers Serratus anterior		Upper trapezius Serratus anterior
Clavicle Forward rotation	50-0°	Long axis of clavicle	Indirectly produced by release of tension on coracoclavicular and costoclavicular ligaments				Upper trapezius
Depression	30-0°	Sternal end of clavicle	Upper trapezius				

Note: Prime mover for upper extremity adduction from full abduction to neutral is the weight of the upper extremity acting at the center of gravity of the upper extremity.

* Primary and secondary controllers act eccentrically.

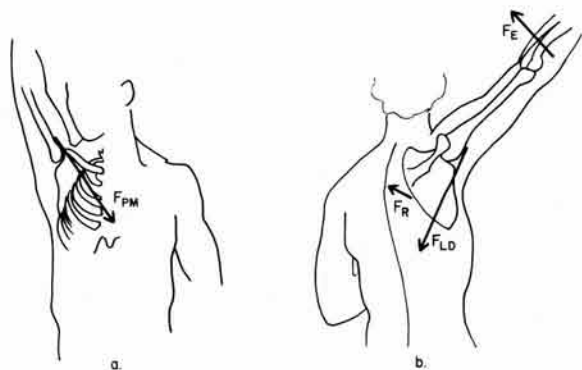


Fig. 5. Muscles during adduction against an externally applied force. F_{LD} , latissimus dorsi; F_{PM} , pectoralis major; F_R , rhomboids; F_E , externally applied force.

the abductors of the humerus. They cannot, however, successfully accomplish their task unless they work in combination with other essential muscles. The infraspinatus, subscapularis, and teres minor of the rotator cuff play a critical role in humeral elevation. These are the muscles that work with the deltoid as a force couple, neutralizing the compression action of the deltoid at the glenohumeral joint (Fig. 3). Furthermore, the infraspinatus and the teres minor participate in the necessary external rotation of the humerus during abduction.

Scapular upward rotation during upper extremity abduction, is performed by the combined actions of the trapezius and the serratus anterior.¹¹ From 0–90° of abduction of the upper extremity, the scapula rotates upwardly approximately 30°. This movement is produced by the upper trapezius and upper digitations of the serratus anterior.² From 90–180° of abduction of the upper extremity, the scapula rotates a further 30°. During the latter part of the range, the lower trapezius and lower digitations of the serratus anterior join with the upper portions of these muscles to form a force couple with an upward rotatory force. It is important to recognize that there are a number of pairs of helping synergists active during these motions. The upper fibers of the serratus anterior and upper trapezius form a pair of helping synergists; the serratus anterior upwardly rotates and depresses the scapula while upper trapezius upwardly rotates and elevates the scapula. The upper and lower trapezius act as another pair of helping synergists; the upper trapezius upwardly rotates and elevates the scapula while the lower trapezius (acting from 30–60° scapular rotation) upwardly rotates and depresses the scap-

ula.^{9,13–15} If all muscles do not work effectively, scapular motion will become unbalanced.

During abduction of the upper extremity as described, the clavicle elevates and then rotates backward along its long axis. Elevation occurs in part because of the force of the upper trapezius which inserts along the lateral one-third of the clavicle.² Clavicular motion also results as a consequence of forces applied elsewhere in the kinematic chain (e.g., to the scapula and humerus). Scapular upward rotation with shoulder abduction causes the clavicle to elevate until the costoclavicular and coracoclavicular ligaments prevent further motion and produces rotation. Clavicular movement occurs without direct muscle action because it is connected with the rest of the shoulder complex kinematically and because of the forces produced by ligaments.

Finally, it is important to recognize that several muscles act at the scapula and humerus to provide stability necessary for the prime movers to work effectively. The teres major is not active during shoulder abduction but does become active during static positions of elevation; its activity increases with increasing load. Inman et al.¹¹ also suggested that the middle trapezius and rhomboid serve to fix the scapula in the plane of motion during abduction but must relax somewhat to allow forward flexion.

In return of the upper extremity from 180° to neutral, all components of the shoulder complex reverse their movements: the humerus adducts and internally rotates; the scapula downwardly rotates (first around an axis of motion near the acromion and then around an axis of motion near the vertebral border); the clavicle rotates forward, then depresses. In this activity, gravity acts as a prime mover. Under the force of gravity, the limb, scapula, and clavicle would fall quickly and without control. Eccentric muscle action is therefore required, not to produce motion, but to control motion. The same muscles lengthen and act eccentrically in this motion as they did concentrically in upper extremity abduction. However, their action is eccentric rather than concentric. In this activity, the relevant muscles are designated controllers rather than movers (Table 6).

If adduction from 180° to neutral is performed against resistance, the shoulder adducts and scapular downward rotators become active (Fig. 5). In this instance, motion of the humerus from 180–90° results from the force of the latissimus dorsi, pectoralis major, and teres minor. From 90°

TABLE 7

Muscle action analysis for upper extremity adduction against resistance, 180–0°

Joint and motion	Range	Axis	Prime movers*	Secondary movers*	Helping synergists	Neutralizers	Antagonists
Glenohumeral Adduction	180–90°	Glenohumeral joint	Latissimus dorsi Pectoralis major Sternal head	Triceps brachii			Supraspinatus Deltoid
	90–0°	Glenohumeral joint	Teres major Latissimus dorsi	Coracobrachialis			
Internal rotation	70–0°	Long axis of humerus	Teres major Latissimus dorsi Pectoralis major Subscapularis	Anterior deltoid			Infraspinatus Teres minor
Scapular Downward rotation	60–30°	Near acromioclavicular joint	Latissimus dorsi Rhomboid Levator scapulae	Pectoralis minor			Lower trapezius Upper trapezius Serratus anterior
	30–0°	On spine of scapula near vertebral border	Rhomboid Levator scapulae Lower trapezius	Pectoralis minor			Upper trapezius Serratus anterior
Clavicular Rotation	50–0°	Long axis of clavicle					
Depression	30–0°	Sternal end of clavicle	Subclavius			Intercostals and/or abdominus oblique may act to prevent elevation of the rib cage depending on force of activity	Upper trapezius

Note: Resistance to these muscles is applied on the humerus in an upward direction.

* Prime and secondary movers act concentrically.

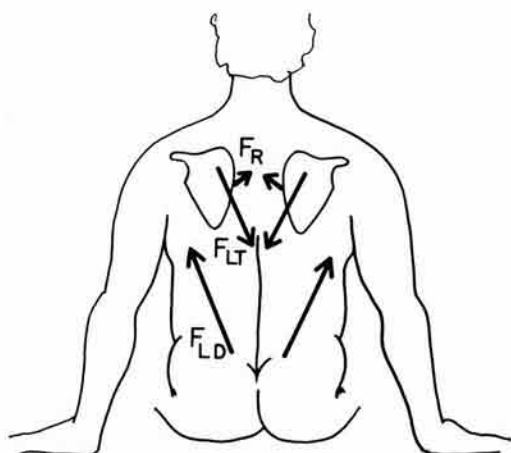


Fig. 6. Muscles acting during a sitting push-up. F_{LD} , latissimus dorsi; F_{LT} , lower trapezius; F_R , rhomboids.

to neutral, the latissimus dorsi and teres major will continue to exert adductor forces; the pectoralis major would predominantly exert a horizontal adduction force and hence is no longer a prime mover for this motion (Fig. 5). Because the latissimus dorsi, teres major, and pectoralis major (from 180–90°) also act as shoulder extensors, muscle action must be exerted to prevent extension as opposed to straight adduction. The pectoralis major (clavicular head) may act as a neutralizer for this extension after 90°. The action of the latissimus dorsi also produces scapular downward rotation and depression by its action on the scapula through the humerus. These motions may be enhanced by the direct actions of the rhomboids and levator scapulae on the scapula. Further assistance in downward rotation is provided by the lower trapezius during scapular rotation from 30° to neutral. It is important to notice the pairs of helping synergists that participate in scap-

ular downward rotation: the rhomboids and lower trapezius retract and depress the scapula, the levator scapulae retracts and elevates the scapula. In summary, forceful downward movement of the humerus requires action of a different group of muscle acting both at the humerus and at the scapula than does simple return of the upper extremity to neutral from abduction (Table 7).

In a sitting push-up the upper extremity and entire shoulder complex is forcefully depressed. Because the limb cannot move downward, the actively contracting muscles cause the body to elevate relative to the humerus. The prime movers thus act in reverse action. This is an example of a closed kinematic chain. Prime movers are the latissimus dorsi, pectoralis major, and to a lesser extent the lower trapezius.¹⁹ These muscles act bilaterally and in reverse action; they move the trunk relative to the humerus in contrast to their normal action moving the humerus relative to the trunk (Fig. 6). Participation of other muscles will depend upon how the motion is carried out. If the humerus is not permitted to internally rotate, the external rotators must act in normal action. The rhomboids and lower trapezius assist in depression and downward rotation of the scapula in relation to the trunk (Table 8). The shoulder abductors and rotator cuff muscles act as stabilizers, controlling scapulohumeral alignment.¹⁹

In this short paper we have not discussed postural muscles that provide stability of the body for upper extremity movement. The action of postural muscles, or stabilizers, varies depending on body position in space. The muscles that maintain stability will depend on the relationship of body alignment to the line of gravity at any given time. Hence stabilizers are variable and dynamic.

TABLE 8
Muscle action analysis for a sitting push-up

Joint and motion	Range	Axis	Prime movers*	Secondary movers	Helping synergists	Neutralizers	Antagonists
Trunk elevates relative to humerus	variable	No axis; translatory motion	Latissimus dorsi Pectoralis major, sternal		Latissimus dorsi and Pectoralis major	Infraspinatus and Teres minor; neutralize internal rotation so the humerus remains neutral. Abdominals neutralize any tendency of latissimus dorsi to anteriorly tilt the pelvis	Deltoids Biceps brachii Triceps brachii

Note: Resistance is the weight of the body minus the upper extremities.

* Prime and secondary movers act bilaterally and in reverse action.

CONCLUSION

The movement of the shoulder complex is the sum of movement of all the joints. Too often it is attributed solely to the glenohumeral joint. Clinically, it is essential to evaluate and treat the entire shoulder complex in order to improve upper extremity function.

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