Biomechanics

Muscular Force and Biomechanical Implications

William L. Cornelius, Ph.D.
Associate Professor of Education
University of North Texas

Understanding basic concepts of biomechanics continues to be an important consideration for the gymnastics practitioner. Command of these anatomical and mechanical ideas may be the essence of constructively dealing with gymnastics movements. Using what has been scientifically established as truth provides the coach and athlete with an invaluable tool in striving for artistic performance. Actually, there are not that many different biomechanical concepts and principles needed by the practitioner to make an impact on the analysis of a specific motor skill (Kreighbaum and Barthels, 1996). One example of an important area of consideration deals with the internal muscle force produced during a performance.

Internal Muscular Force

Muscular strength is considered to be the ability to do work against resistance or the capacity to exert force (Arnheim and Prentice, 1993) and is derived through muscle tension produced during muscle contraction. The outcome is a force internal to the human system. This internal force produces tension on the skeletal system, resulting in angular motion about a joint. Examples of this phenomenon are shown in Figures 2-4 by furnishing illustrations of gymnastics movements and associated muscle forces.

Resolution of force

Resolution of force or vector resolution is an example of a biomechanical technique that provides a means of establishing the two component forces directly associated with a net force. This net force can be responsible for a movement and is known as the resultant force (Figure 1). An explanation is now possible for why a particular force results in a specific movement when the resultant vector is known. This leads to resolving the component forces. Component forces provide a clearer picture of what the resultant force contributes to the performance.

Component forces

Angular and stabilizing vectors represent the two components derived from a resultant force. Figure 1 illustrates the relationship between the resultant vector and component forces. When dealing with internal forces created from muscle contractions, the resultant force (F) is applied at the muscle insertion located on the attachment (apophysis) of the bone to be mobilized and is directed toward the muscle origin. This resultant force is directed through the belly of the particular muscle. The angular vector is directed perpendicular to the bone that is being moved and the stabilizing vector is directed along the same bone, into the joint (Kreighbaum and
Consequently, the angular force component is responsible for moving the skeletal part, while the stabilizing force component serves as a means of adding to joint integrity (stability). The angular vector (F1) and stabilizing vector (F2) begin from the point of force application and are directed at right angles, one to the other. Figures 2-4 provide examples of resultant vectors and their component vectors, originating from concentric muscle contractions during the performance of gymnastics skills.

The cast

Initiating a cast on such apparatus as the horizontal bar or uneven bars can require elbow flexion (Figure 2, frames A to B). The biceps brachii muscle acts as one of the primary movers, with elbow flexion occurring around the mediolateral axis in the sagittal plane. Figure 2 (frames a-b) illustrates a relationship between the resultant force (F) of the biceps brachii and the component forces (F1 and F2) during this maneuver. The F1 and F2 vectors demonstrate the direction and magnitude of the angular and stabilizing force components, respectively. Elbow joint stabilization is maximized in frame A because the long hang is the position associated with the initial stage of biceps brachii concentric contraction. Although F does begin moving the lower arm into elbow flexion at frame A, F1 is smaller than F2 because F is slightly less than 20 degrees at the biceps brachii muscle insertion. Consequently, the larger portion of F acts to stabilize the elbow joint at frame A. This relationship begins changing from frame A to B as the angle of insertion progressively increases for the biceps brachii muscle. At frame B the resultant force is approximately 70 degrees to the radius at the biceps brachii insertion and suggests F1 is considerably larger than F2. Consequently, the majority of the resultant force produced by the biceps brachii in frame B is now directed toward moving the lower arm segment at the elbow joint; a smaller portion is focused on stabilizing the joint. It is by this means that the angle of muscle insertion becomes a critical mechanism in producing F1 and F2 magnitudes. The closer the resultant angle of muscle insertion is to 90 degrees, the larger the angular vector for moving a bony segment, and conversely the smaller the stabilizing force vector for improving joint integrity (Kreighbaum and Barthels, 1996).

Stabilizing the shoulder joint can be particularly important when the gymnast is at the
bottom of the swing (frame A) immediately prior to elbow flexion. In this case, the joint experiences distraction with the external force of gravity. Muscle tension produced by such shoulder joint muscles as the rotator cuff are essential in acting to maintain joint integrity. Assistance from these muscles is beneficial because the shoulder joint is inherently lacking in stability when considering the shallow depth of the glenoid fossa and the few ligaments strapping the joint. In fact, the articulating relationship between the humerus and glenoid fossa provide for less than one-third of the humeral head at the shoulder joint. The combined tension force of the rotator cuff muscles, therefore, is particularly suited to limiting the dislocation effect of the gravity force on the shoulder joint in frame A. Biceps brachii muscle tension, across the shoulder joint to its attachment on the upper rim of the glenoid fossa, provides added stability needed for maintaining joint integrity. The extension action at the shoulder joint in frames A to B, from such muscles as the latissimus dorsi and teres major, adds further to the developing tension created across the shoulder joint. The triceps brachii (long head) adds another dimension to stabilizing the shoulder joint as it lengthens during the initial stage of the cast in the two joint action of elbow flexion and shoulder extension (frames A to B). Stability is improved because there are a number of musculotendinous units acting to supplement ligaments as the strap across the shoulder joint.

Gravity can be used as a motive force through part of the cast (Figure 2). An example of this phenomenon occurs in a counter clockwise direction around the bar axis from frame B to C. Internal action forces from muscle contraction result in bar external reaction forces on the gymnast that couple with the gravity force. The force diagram in frame C depicts the anterior deltoid in acting to move the humerus into shoulder joint flexion. The resultant angle of insertion shown in frame C is relatively small; therefore, F1 is relatively small, providing a large stabilizing effect (F2) at the shoulder joint. More muscle fibers must now be recruited subsequent to frame C, when the body begins to move upward against the resistive force of gravity. As the humerus moves further into shoulder joint flexion, however, F1 increases in magnitude while F2 decreases in magnitude. The mechanism for the larger F1 and resulting torque enhancement is the increasing angle of muscle insertion. The resulting increase in F1 provides enhanced torque, but decreasing F2 tends to place more stress on ligaments and other connective tissues providing for joint stability.

The dislocate
The dislocate is a dynamic skill with explosive movement through a large angular displacement. As the gymnast moves toward a pike position below the rings in Figure 3, frame A and b, it is essential to have the cooperation of shoulder complex stabilizing muscles. Shoulder girdle adductors (rhomboids, trapezius 3) and shoulder joint rotator cuff muscles must resist the external force of gravity. The shoulder girdle adductors act to provide a firm scapula base upon which the humerous can function at the glenoid fossa through a large range of motion. This firm base is necessary because the shoulder joint muscles attach on the scapula at their origin; force application is then improved at the humeral insertion points for angular and stabilizing purposes.

The center of gravity translates upward from frame B to C (Figure 3) as the humerous begins moving away from the midline of the body as well as displacing forward (anterior). Humeral head accommodation is again essential in order for the humerus to be moved toward frame C and beyond. This requires that the serratus anterior and trapezius 2 and 4 upwardly rotate the scapula, while the serratus anterior and pectoralis minor abduct the scapula. These shoulder girdle muscles act as scapula stabilizers in frames C and D as the humerus moves in a diagonal pattern (abduction and transverse abduction). This part of the dislocate provides an example of overcoming the resistive force of gravity when moving from below the rings to a point above the rings in frames B-D. The supraspinatus muscle acts as a prime mover during abduction of the humerus when initiating the dislocate from frame B to C. Frame C illustrates a force diagram that helps depict the angular and stabilizing force components elicited by the supraspinatus muscle. Frame C illustrates the resultant internal tension force is approximately 45 degrees to the head of the humerus at the greater tuberosity insertion point (frame D). This angle of the resultant force suggests the angular (F1) and stabilizing (F2) vector components are equal. As the humerus moves progressively into abduction and transverse adduction, from frame B to D, the supraspinatus angular force component increases while the stabilizing force component decreases. Reliance on the supraspinatus muscle in frame C is apparent because the medial deltoid is less effective as an abductor when the humerus is below 60 degrees to the trunk (Kreighbaum and Barthels, 1996). The medial deltoid primarily acts to stabilize the glenohumeral joint in frames B to C. Both the medial deltoid and the supraspinatus contribute in frames B through E to moving the humerus into abduction in preparing body
alignment for the downward swing in frames E to F. Both muscles are essential in neutralizing the effects of gravity by reducing the separation between the humerus and the glenoid fossa. When reaching the bottom of the swing in frame F, muscles of the rotator cuff, and other muscles crossing the shoulder joint, act as strapping mechanisms for improving joint integrity. The effects of gravity are particularly stressful to the shoulder joint at the bottom point for individuals experiencing shoulder joint instability. Such conditions as the rotator cuff impingement syndrome and biceps brachii tendonitis (near the origin) are examples of trauma that create shoulder joint instability.

**The takeoff**

Extension is the main knee joint action at the point of takeoff in vaulting (Figure 4). The quadriceps muscle group serves as the primary mover in this maneuver, around the mediolateral axis and along the sagittal plane. A force diagram in frame A acts as a means of describing the relationship between the resultant quadriceps force (F), angular force component (F1), and the stabilizing force component (F2).

The takeoff is a point in the total vaulting skill where the gymnast has an opportunity to increase or decrease angular momentum (Cornelius, 1994). Angular momentum is produced in Figure 4, frame A, for vaulting preflight (frames B-D). The production of angular momentum is dependent upon the magnitude of the overall internal action force established in frame A by muscles crossing the shoulder, hip, knee, and ankle joints. This in turn creates the external reaction force issued from the board. Frame D is the second point in a vault where angular momentum can be influenced by an external force for subsequent postflight. Shoulder girdle elevation is the mechanism for repulsion and is linked with shoulder girdle elevator muscles, such as trapezious 1 and 2, levator scapula, and rhomboids. Consequently, the total vault is highly dependent upon increasing the magnitude of the angular force component (F1) at board takeoff ant at vaulting horse repulsion.

The net force produced by the quadriceps during knee joint extension can be improved by a moveable patella. The patella functions as a mechanical pulley at the knee joint (Figure 4, frame A) and possesses the capacity to change the angle of muscle insertion at the tibial
tuberosity (point of quadriceps insertion). Without this accommodating effect from the patella, there would be reduced joint range of motion in knee flexion and extension and certainly torque about the knee would be reduced. Changing patellar positions can move the angle of muscle insertion to a more favorable resultant (F). This in turn can increase F1 and decrease F2, providing a greater amount of the total force produced by the quadriceps for increasing the angular vector (F1). For example, the quick stretch of the quadriceps musculotendinous unit during knee flexion (frame A) in initial board contact, moves the patella downward in the intercondylar gomeral groove to a position that increases the angle of muscle insertion at the tibial tuberosity. This results in an increase in F1 and improved torque for the explosive takeoff maneuver.

**Summary**

Understanding the contribution made by the component vectors of a muscle contraction will greatly assist the practitioner. There is an improved understanding of why an individual moves in a particular manner when the line of action of the internal muscle force is known. Exact or precise points of muscle attachments and the technical names for these locations are not essential; in fact, only the line of action is needed. Consequently, a mental image of the muscle location and line of action is quite useful. This provides relationships between the resultant force and associated force components acting on a skeletal segment. The practitioner is now provided with greater insight into ways in which the internal muscle force can assist in changing gymnastics performance.

**References**


*Figures 2-4 are based on drawings by James Stephenson in the 1984-88 USA Gymnastics Junior Olympic Age Group Compulsories.*

This article appears in the January 1997 issue of *Technique*, Vol. 17, No. 1.