Mechanisms of Shoulder Injuries

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In this article, we discuss our review of 284 shoulder injuries that were seen and treated arthroscopically during a five-year period. All of the injuries were related to the athletes' particular sport. We describe the biomechanical basis for these injuries and review the data gathered on the forces involved in the act of throwing.

Key Words: *Athletic injuries, Shoulder, Sports.*

The shoulder joint has long been an enigma to clinicians because of their inability to locate, identify, and treat its minor injuries without arthrotomy. The introduction of the arthroscope enables the orthopedist to view the shoulder joint complex. The glenohumeral joint, the subacromial bursal space, and even the acromioclavicular joint can be examined visually. This visual capability has added insights into the pathological factors associated with shoulder instabilities and even has allowed modification of both repair techniques and repair philosophies. We currently are seeing high-performance athletes returning to their sports participation after outpatient arthroscopic surgery to correct defects that, in the past, would have meant a poor prognosis for doing so. In this article, we will discuss only soft tissue injuries that are treated athroscopically.

The four joints that make up the shoulder complex are the glenohumeral, the acromioclavicular, the scapulothoracic, and the sternoclavicular joints.[1] In this article, we present the statistics of glenohumeral joint injuries that we have seen arthroscopically over the past five years. These injuries were in athletes, the majority of whom participated in baseball. The act of throwing seems to be one of the major precipitators of shoulder injury.

INJURIES

We will analyze a specific set of soft tissue injuries, all of which are treated athroscopically and which have a logically derivable biomechanical description of the injury mechanism. These are injuries to the glenoid labrum, the rotator cuff, and the long tendon of the biceps brachii muscle. These injuries can be isolated or they can occur in almost every possible combination.

Labrum Tears

The glenoid labrum is a fibrous tissue mass attached to the periphery of the glenoid fossa. Its function has not been well defined, but it serves as a buffer to help center the humeral head. To allow the shoulder its range of mobility, the glenoid fossa is shaped like a shallow dish having a much larger radius of curvature than the humeral head. Unlike a normal ball-and-socket joint, therefore, the humeral head is capable of linear movement across the surface of the glenoid fossa in addition to its rotational freedom. The labrum performs some shock-absorbing functions relative to this linear movement.

Tears of the labrum are very common. They can occur superiorly or inferiorly in both the anterior and posterior sections. The tear can be produced acutely or chronically. The mechanism in each type is different. Acute tears are well-defined rents in the tissue, whereas chronic tears are severely frayed, and the tissue looks "beat up." In many instances, tears of the glenohumeral ligaments occur in combination with anterior labrum tears, but, because of difficulties in the visual examination and identification of these glenohumeral structures, not all of these instances have been recorded. The location of the tears is identified by these four quadrants: anterior-inferior, anterior-superior, posterior-superior, and posterior-inferior.

Rotator Cuff Tears

In general, rotator cuff tears seen and treated arthroscopically are incomplete tears showing on the under surface of the muscle. The rotator cuff is composed of four muscles: the subscapularis, the supraspinatus, the infraspinatus, and the teres minor. Athroscopic viewing of the glenohumeral joint reveals no well-defined demarcations between the supraspinatus, the infraspinatus, and the teres minor muscles to allow easy identification. The subscapularis muscle, which provides dynamic support for medial (internal) rotation, has not been reported to be involved in the rotator cuff tears that have been seen during surgery. Both separate and combination tears have been recorded for the supraspinatus, the infraspinatus, and the teres minor muscles. Combination tears were found only in adjacent muscles, never separately in the supraspinatus and the teres minor muscles.

Biceps Brachii Tendon Tears

The originating tendon of the long head of the biceps brachii muscle lies in the bicipital groove of the humerus, protected and stabilized by the transverse humeral ligament. This strong tendon crosses the joint space to the superior aspect of the glenoid labrum where the tissue becomes integral with the superior labrum. Tears of the biceps brachii tendon are observed rarely in the absence of a tear in the anterior-superior labrum because of the integral relationship between the tissues of these two structures. As a result, we will discuss these tears

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TABLE 1
Labrum, Biceps Brachii Tendon, and Rotator Cuff Injuries

Sport (n)	Labrum n (%)	Biceps Brachii n	Rotator Cuff n (%)	Labrum, Biceps Brachii n (%)	Labrum, Rotator Cuff n (%)	Labrum, Biceps Brachii, Rotator Cuff n (%)	Biceps Brachii, Rotator Cuff n (%)
Baseball (178)	48 (27.0)	0	28 (16.0)	8 (4.5)	75 (42.0)	17 (9.5)	2 (1.0)
Football (42)	24 (57.0)	0	1 (3.0)	6 (14.0)	8 (19.0)	3 (7.0)	0 (0.0)
Swimming (10)	8 (80.0)	0	1 (10.0)	1 (10.0)	0 (00.0)	0 (0.0)	0 (0.0)
Tennis (15)	6 (40.0)	0	1 (6.5)	1 (6.5)	7 (47.0)	0 (0.0)	0 (0.0)
Weight lifting (13)	5 (39.0)	0	3 (23.0)	2 (15.0)	2 (15.0)	1 (8.0)	0 (0.0)
Racquetball (4)	2 (50.0)	0	1 (25.0)	1 (25.0)	0 (00.0)	0 (0.0)	0 (0.0)
Other (22)	13 (59.0)	0	3 (14.0)	1 (5.0)	4 (18.0)	1 (4.0)	0 (0.0)

as occurring to the biceps tendon-labrum complex. In many cases, the tendon of the long head of the biceps brachii muscle has been found to be shredded severely, indicating repeated trauma.[2]

HISTORY OF INJURIES

A recent review of our clients' records indicated a total of 297 athletes who were treated arthroscopically for shoulder problems in a five-year period (1980–1985). Table 1 shows the combination of pathological conditions found relative to the athletes' primary sports in 284 cases. There were 178 injuries (60%) related to baseball and 42 (14%) related to football. Of the 178 baseball-related injuries, 115 (65%) of them were to pitchers; of the 42 football injuries, 12 (29%) were to quarterbacks. These high percentages indicate that the athletes who frequently engage in throwing experience shoulder injuries most often. The high percentage of baseball players is because all baseball players throw the ball, whereas, in football, only the quarterbacks throw. Also, 7 (58%) of the 12 quarterbacks tore their rotator cuff in combination with labrum tears, whereas only 5 (17%) of the remaining 30 football players had rotator cuff lesions. In contrast, 84 (73%) of the 115 baseball pitchers had rotator cuff lesions, and 38 (60%) of the 63 players in other positions had rotator cuff injuries. This difference in percentages of injuries indicates that the "throwing athletes" are most likely to tear the rotator cuff. The high percentage of injuries in nonpitchers might indicate that nonpitchers throw very hard but less frequently than pitchers and, therefore, probably are not "warmed up" properly. The data presented later in this article will support this hypothesis.

The incidence of isolated rotator cuff tears appears to be high only in baseball players and weight lifters. Combined tears of the cuff and labrum, however, are common in athletes participating in baseball, tennis, and weight lifting. The records of only 13 weight lifters were reviewed, but they evidenced a variety of tissue injuries resulting from the size of the forces transmitted across the shoulder. No soft tissue structure is safe from injury.

Notable is the virtual absence of rotator cuff tears in the 10 swimmers included in this review. Swimming has its own unique, completely separate set of forces acting on the shoulder and, as we see in our patients, these forces produce mostly isolated labrum tears. When the location of these tears is investigated, the nondiscriminatory nature of these injuries becomes apparent. The injury is scattered across all quadrants of the labrum. Of 10 swimmers, only one had a rotator cuff tear, and one had a biceps brachii tendon tear. These data were misleading because neither of these injuries were produced from swimming. The swimmer with the rotator cuff tear was injured while playing softball, and the biceps brachii tear stemmed from sources other than swimming. Thus, the documentation of the complete history of injuries is important. The primary sport of both of these athletes was swimming; however, in both cases the injury was produced by another sports activity. Our data have been scrutinized to ensure the validity of the injuries. Those injuries that resulted from "falling off a bicycle" or "falling out of a golf cart" do not constitute an injury related to the sport.

Injuries incurred while training for the primary sport, but not while participating in the primary sport, create some confusion in identifying the mechanism of injury. In our review, the only training regimen that appeared consistently to be related to injury was weight training. Because weight training is a valid process that should accompany all sports, injuries generated by it must be recorded for the sport being trained for, but they must be labelled distinctly from others. None of the football injuries seen in our review occurred directly as a result of weight training. This finding, however, does not preclude the possibility of chronic deterioration of the soft tissues of weight lifters. No real difference exists in the distribution of injuries between weight lifters and football players. The question, then, is whether many of the football injuries are a direct result of weight training. Of the 42 football players in our review, 10 had an insidious onset of symptoms with no single episode of trauma related to the injury. Of the 13 weight lifters, 10 experienced an insidious onset of symptoms. This evidence warrants our serious consideration of the need to study the weight training techniques being used. Many of the hazards the football player is exposed to are similar to those of weight lifting. Injuries where the mechanism of injury was identifiable were from direct trauma, such as falling on a shoulder, tackling, or throwing.

BIOMECHANICAL ANALYSIS

An understanding of the nature of the injuries associated with an action or sport, combined with a measurement of the environment and levels of stress and motions imposed on the joints, allows an understanding of the mechanism(s) causing specific soft tissue structures to be damaged. The act of throwing has been shown to be one of the most consistent in producing rotator cuff tears with and without other, associated pathological conditions.

A study of the pitching mechanism was conducted that outlined the forces that the shoulder is subjected to during the act of pitching a baseball.[3] Both the nature and the magnitude of the forces have different effects on the tissues in the joint. The following discussion relates the measured forces to the three classes of injuries (labrum, rotator cuff, biceps brachii tendon) discussed above. All aspects of these forces must be considered. The magnitude of the forces is of primary concern but equally important is the rate of change of the magnitude and the time duration of the forces. Figure 1 shows the relative size of the moments of force exerted during the act of pitching to control humeral elevation. In all measurements of high-speed motion, the amount of energy being exerted on a structure must be estimated on the basis of the approximate dimensions of the moving parts and the ball. The energies acting on humeral elevation, the moment, are shown to be in excess of 600 in-lb. This energy is the equivalent of a force of greater than 600 lb (270 hg) acting at a distance of 1 in (2.54 cm) from the center of rotation of the humerus about the glenoid fossa.

Figure 2 shows two combined rotational velocities of the humerus. The torsion velocity of the humerus is the rate of rotation of the humerus about its long axis; the horizontal adduction velocity is the rate of rotation of the humerus about the glenoid fossa in a horizonal plane. The point of minimum velocity for both is the ball release. The apparent negative velocity is a function of an offset in our data and can be considered to be essentially zero. Figure 2 illustrates the mechanism of transferring momentum from adduction to medial humeral rotation. Medial rotational velocity continues to increase even after the ball release and is shown to exceed 6,000°/sec when a "fast ball" is thrown.

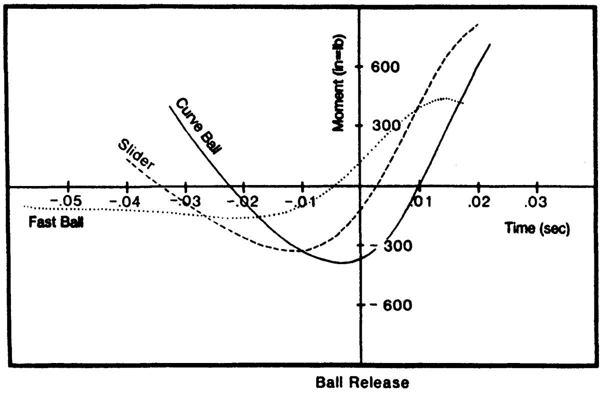

Fig. 1. The relative size of the moments of force exerted, during the act of pitching, to control humeral elevation.

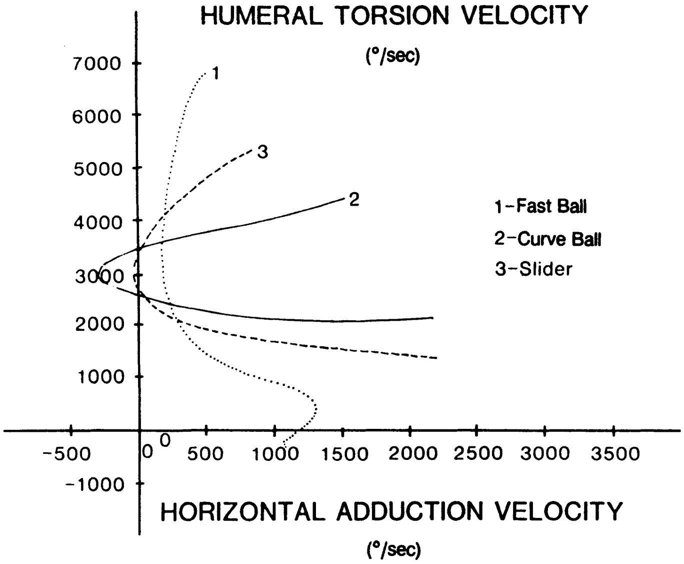

Fig. 2. The rate of humeral torsion (°/sec) versus the rate of humeral horizontal adduction (°/sec).

Labrum Tears

Labrum tears are common injuries in all of the sports that we reviewed. In the throwing athlete, the complex combinations of high-speed rotational velocities that are generated jeopardize the articulating surfaces (Fig. 2). With the relatively high acceleration forces required to accelerate the ball from 0 to 90 mph in 50 to 80 msec, any lack of strength in a segment of the stabilizing muscles will allow the humeral head to articulate with the glenoid labrum rather than with the center of the glenoid fossa. This abnormal articulation can tear the labrum during the primary acceleration phase of throwing. In addition to this hazard, the rapid forward motion of the arm at ball release must be decelerated. If the rotator cuff muscles are not balanced properly and the glenohumeral joint stabilized adequately, the deceleration forces can cause the joint to distract. Any off-centering of the humeral head during this distraction will cause it to be reseated off-center, placing the labrum in jeopardy for injury.

Generally, any force that can shift the humeral head to the rim of the glenoid fossa will endanger the labrum. This danger explains a predominance of labrum tears in athletes who use their arms in sports. Traumatic injuries that "jam" the shoulder unpredictably do not allow clinicians the luxury of a neat analysis of which quadrant of the labrum most likely would be injured. If clinicians deal strictly with the known hazards of a sport where the injuries are incurred intrinsically, however, the mechanisms can be hypothesized more readily. Table 2 lists the most common labrum tear locations in the baseball players we studied. These statistics have been divided into professionals and nonprofessionals and then further divided into pitchers, catchers, and others. The majority of tears are restricted to the anterior-superior labrum. The tears most often are propagated posteriorly and least often inferiorly. This table highlights 115 (78%) of a total of 148 labrum tears. No throwing athlete had a combined tear of the anterior-inferior and posterior-inferior quadrants. These locations indicate a mechanism of injury that causes the humeral head to move anteriorly and superiorly.

During the acceleration phase of throwing, the anterior deltoid and the pectoralis major have been shown to be active (see the article by J. Perry et al in this issue). The muscles impose a force on the humerus that pulls the humeral head anteriorly. Those forces opposing this anterior motion of the humeral head, exerted by the posterior rotator cuff muscles, are inhibited somewhat by their antagonistic role. The anterior forces in combination with the high medial rotational velocities of the humerus tend to allow the humeral head to move laterally over the anterior labrum. Unfortunately, substantiation of this theory in the laboratory would be extremely difficult because these injuries occur during high-speed, high-energy events.

Rotator Cuff Tears

The causes of shoulder injuries relative to the athlete's primary sport have been described above. As we discussed, the majority of rotator cuff injuries are produced in the throwing athlete. Of the 178 baseball players we reviewed, 122 (68%) had rotator cuff tears. Of the 122, 100 (82%) had supraspinatus muscle involvement: 75 (61%) of these injuries were limited to the supraspinatus muscle alone, and 25 (20%)

TABLE 2
Most Commonly Found Patterns of Labrum Tears in Baseball Players

Quadrant[a]	Professional			Nonprofessional		
	Pitchers n (%)	Catchers n (%)	Other n (%)	Pitchers n (%)	Catchers n (%)	Other n (%)
AS	22 (40.8)	1 (25.0)	6 (40.0)	15 (50.0)	3 (50.0)	15 (68.2)
AS-PS	16 (29.6)	1 (25.0)	5 (33.4)	10 (33.4)	2 (33.3)	4 (18.2)
AS-AI	8 (14.8)	1 (25.0)	2 (13.3)	1 (3.3)	1 (16.7)	2 (9.1)
PS	8 (14.8)	1 (25.0)	2 (13.3)	4 (13.3)	0 (0.0)	1 (4.5)
TOTAL	54	4	15	30	6	22

[a] AS = anterior-superior, PS = posterior-superior, AI = anterior-inferior.

of these injuries were combined supraspinatus and infraspinatus muscle involvement. This finding is important because the data in Figure 1 show the large deceleration moments required to maintain the shoulder abducted to 90 degrees. These deceleration moments occur both before and after ball release, which explains the possibility of tears in the supraspinatus, one of the two primary muscles used to abduct the arm in the scapular plane.[4] Because little demarcation is seen between the supraspinatus and the infraspinatus tendons when viewed arthroscopically, the tendons tend to be continuous, and supraspinatus tears communicate into the infraspinatus portion. Deceleration (eccentric) contractions of a muscle tend to be large but of short duration. These deceleration actions are proposed to be the mechanism for rotator cuff tears.[3] This proposal can be justified in some sense by considering a sport that does not involve deceleration of the muscles. Swimming is almost devoid of deceleration forces, and our data show no rotator cuff tears in the swimmers we studied who were injured as a result of participation in the sport.

"Biceps Tendon-Labrum Complex" Tears

The third class of injury is what Carson et al call tears of the "biceps tendon-labrum complex."[2] These injuries include a tearing of the biceps brachii tendon and of either the anterior-superior labrum or the anterior-superior and posterior-superior labra. The tendon of the long head of the biceps brachii muscle generally is shredded where it attaches to the rim of the glenoid fossa. One possible mechanism of injury has been proposed to be the high deceleration forces imposed on the biceps brachii muscle when decelerating the rate of elbow extension during throwing.[2] As shown in Figure 2, the elbow moves at 6,000 °/sec, and this movement must be stopped abruptly. The forces of deceleration are transferred to the body across the shoulder joint by the rotator cuff muscles. The high magnitude of these forces also must be transferred across the humeral head by the biceps brachii tendon. This is the proposed mechanism for tears of the biceps brachii tendon-labrum complex.[2] One of the functions of the long head of the biceps brachii tendon can be viewed as preventing shoulder joint distraction to allow effective deceleration of elbow extension. This function has been demonstrated by electrical stimulation of the biceps brachii muscle while the glenohumeral joint was under arthroscopic visual examination.

CONCLUSION

Our discussion has dealt with proposed mechanisms for glenohumeral joint injuries that generally are treatable arthroscopically. These mechanisms are hypothetical, but the kinds of forces found to exist in specific sports have been shown to be capable of producing these injuries. We hope to continue to document the correlation of mechanisms of injury to the pathological conditions we observe to 1) help to improve our capability to predict the in vivo mechanisms of shoulder injury in athletes and 2) help prevent their occurrence.

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