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Biceps Activity During Windmill Softball Pitching

Injury Implications and Comparison With Overhand Throwing

Idubijes L. Rojas,* LCDR Matthew T. Provencher,† MD, MC, USN, Sanjeev Bhatia,§ Kharma C. Foucher,* PhD, Bernard R. Bach Jr,§ MD, Anthony A. Romeo,§ MD, Markus A. Wimmer,* PhD, and Nikhil N. Verma,§‡ MD

*From the *Department of Orthopedic Surgery, Rush University Medical Center, Chicago, Illinois, †Naval Medical Center San Diego, San Diego, California, and §Midwest Orthopaedics, Rush University Medical Center, Chicago, Illinois*

Background: Windmill pitching produces high forces and torques at the shoulder and elbow, making the biceps labrum complex susceptible to overuse injury. Little is known about the muscle firing patterns during a windmill pitch.

Hypothesis: Biceps muscle activity is greater during a windmill pitch than during an overhand throw.

Study Design: Descriptive laboratory study.

Methods: Seven female windmill pitchers underwent motion analysis and surface electromyography evaluation of their biceps muscles during windmill and overhand throwing. Marker motion analysis, muscle activity, and ball release were captured simultaneously. Surface electromyography trials were collected and related to the athletes' phases of pitching and throwing, identified based on predefined softball and baseball pitching mechanics.

Results: Throws were of similar velocity (24 m/s, 53 mph, $P = .71$), but peak biceps brachii muscle activation during the windmill pitch was significantly greater than during the overhand throw when normalized (38% vs 19% manual muscle test, $P = .02$). The highest muscle activity occurred at the 9-o'clock phase of the windmill pitch, during which the biceps brachii undergoes eccentric contraction. In the overhand throw, the highest level of biceps activity occurred during arm cocking.

Conclusion: In female athletes, biceps brachii activity during the windmill pitch is higher than during an overhand throw and is most active during the 9-o'clock and follow-through phases of the pitch.

Clinical Relevance: Repetitive eccentric biceps contractions may help explain the high incidence of anterior shoulder pain clinically observed in elite windmill pitchers. Injury prevention and treatment mechanisms should focus on the phases with the highest muscle activity.

Keywords: biceps brachii; long head biceps; bicipital tendinitis; tendinitis; softball; windmill pitch

Fast-pitch softball is one of the most popular female athlete team sports in America.[7,17] The Amateur Softball Association, the national governing body that selects athletes for the US Olympic team, reports that 1.3 million fast-pitch players were registered with them in 2008, and it has been estimated that the total number of female adolescents competing in fast-pitch softball in 2008 was upwards of 2.5 million.[17] In spite of fast-pitch softball's immense popularity at the high school and collegiate levels, there remains a scarcity of sports medicine research on the game's most notable activity: the windmill pitch. The conventional belief in softball has been that the underhand throwing motion places little stress on the arm and pitching-related injuries among windmill throwers are rare.[13] Unlike baseball's governing bodies, the Amateur Softball Association has no rules limiting the number of innings pitched at any level of play. Moreover, softball teams usually carry a lesser proportion of pitchers on their

‡Address correspondence to Nikhil N. Verma, MD, Rush University Medical Center, Department of Orthopedic Surgery, 1725 W Harrison, Ste 1063, Chicago IL 60612 (e-mail: nverma@rushortho.com).

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TABLE 1
Description of Windmill Pitching Phases

Phase	Position	Motion
1	Windup	First ball motion forward to 6 o'clock, varied from subject to subject; arm extension ranged from 0° to 90°
2	6 to 3 o'clock	Body weight placed on ipsilateral leg, trunk faced forward, arm internally rotated and elevated at 90°
3	3 to 12 o'clock	Body weight transferred forward, body begins to rotate toward pitching arm, arm is elevated to 180°, and the humerus is externally rotated
4	12 to 9 o'clock	Body remains rotated toward pitching arm, the arm is adducted toward next position, and body weight lands on the contralateral foot
5	9 o'clock to ball release	Momentum is transferred to adducted arm, body is rotated back to forward position, and more power is transferred to arm just before ball release
6	Follow-through	Arm contacts lateral hip and thigh, forward progression of humerus is halted, and ball release to completion of pitch

TABLE 2
Description of Overhand Throwing Phases

Phase	Position	Motion
1	Windup	Body is coiled to propel the ball
2	Stride	Body weight placed on ipsilateral leg, and legs are spread wide; placement and rotation of feet are critical
3	Arm cocking	Body weight placed on contralateral leg, arm assumes a 90° angle from trunk, elbow cocks to about 90° as trunk begins to rotate forward, and shoulder begins to rotate backward
4	Arm acceleration	Trunk continues to rotate forward, and pitcher whips arm forward to fire ball toward plate
5	Arm deceleration	Arm continues to move until the end of the forward motion
6	Follow-through	Trunk moves forward and down; maximum inward rotation of throwing arm occurs

rosters than do their baseball counterparts, which translates into more innings pitched per athlete.[16] Because the best pitcher on a high school or college team pitches the majority of games, competitive female pitchers often pitch as many as six 7-inning games during a weekend tournament—the equivalent of 1200 to 1500 pitches[17] in as little as 3 days.

The softball windmill pitch is becoming increasingly recognized as a cause of notable shoulder injury among female collegiate and professional softball teams.[9,10,14,17,18] In an athletic trainers' survey of 8 top-ranked female collegiate softball teams, Loosli et al[13] found a 45% incidence (11/24) of time-loss injuries in a single season among softball pitchers. Of the time-loss injuries, 45% (5/11) were injuries to the shoulder and elbow, including bicipital and rotator cuff tendinitis and strain—both examples of overuse injury.[13,14,17,18] A common symptom among softball pitchers is anterior shoulder pain. It has been shown that windmill pitching produces high forces and torques at the shoulder and elbow, making the biceps labrum complex susceptible to overuse injury.[1] The windmill pitch demands that the biceps labrum complex resist glenohumeral distraction and produce elbow flexion torque to control elbow extension during the vigorous windmill acceleration and deceleration.[1]

An improved knowledge of the muscle firing patterns during arm movement would permit a more specific conditioning program to help improve performance, reduce injury, and aid in injury rehabilitation in windmill pitching. Although upper extremity electromyography has been conducted for several overhand throwing motions, particularly the baseball pitch,[8,9,11,12] little is known about the muscle firing patterns during a windmill pitch.[14] Maffet et al[14] investigated the softball windmill pitch and described the phases and the muscle firing patterns of 8 shoulder muscles; however, the biceps brachii was not included. The purposes of this study were to determine the muscle activity of the biceps during specific phases of a windmill pitch and to compare the overall biceps activity between the windmill pitch and an overhand throw. Because of the specific ball-release mechanics, our hypothesis was that the overall biceps brachii activity would be greater in a windmill pitch during minimum elbow flexion versus an overhand throw during maximum elbow flexion.

MATERIALS AND METHODS

Three collegiate and 4 professional female pitchers with a mean age of 22 years (range, 19-26; SD, 3 years) consented to participation in an institutional review board–approved protocol. None had a previous shoulder injury or current shoulder complaint that would interfere with their ability to perform at full pitching and throwing capacity. The mean height was 1.7 m (range, 1.6-1.8 m; SD, 0.1 m), and the mean weight was 71 kg (range, 56-89 kg; SD, 10 kg). The pitchers all were right-hand dominant. None of the softball players were aware of the hypothesis of the study.

All testing was carried out in our human motion analysis laboratory. Eight retro-reflective markers were strategically placed over the greater tuberosity, lateral humeral epicondyle, styloid process of the radius, iliac crest, lateral femoral epicondyle, and lateral malleolus of the ipsilateral leg, as well as on the medial femoral condyle and medial malleolus of the contralateral leg. A regulation collegiate softball was wrapped with reflective tape that allowed for the precise 3-dimensional location of the ball during the entire pitch and to record the exact time of release. A radar gun (Stalker Sport, Plano, Texas) was used to obtain the velocity of the ball as it left the pitcher's hand. Marker motion was captured using a 4-camera optoelectronic

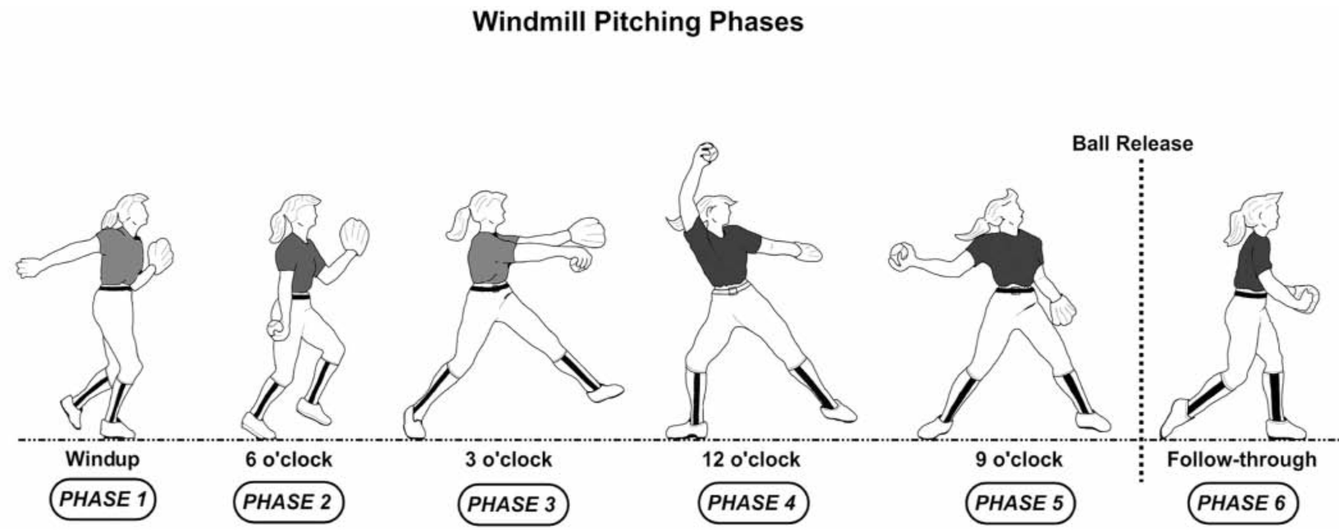

Figure 1. Windmill pitching phases. Adapted with permission from Maffet et al.[14]

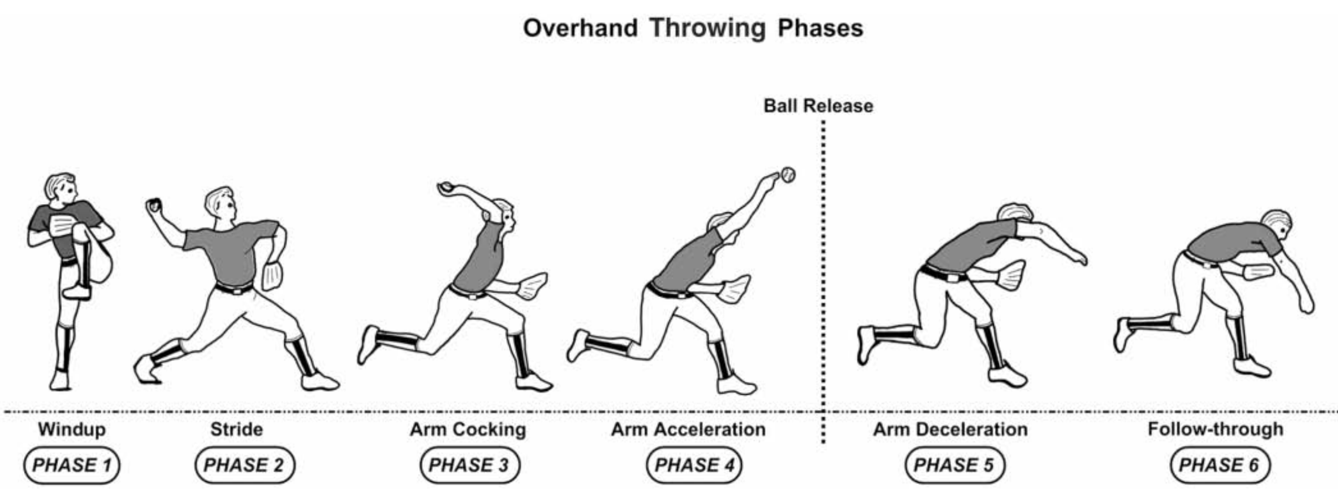

Figure 2. Overhand throwing phases. Adapted from Escamilla et al.[4]

system (Qualisys North America Inc, Charlotte, North Carolina) at 120 Hz.

The surface electromyography (sEMG) of biceps brachii muscle activity from the subjects' pitching arms was collected during each trial using a TeleMyo transmitter and receiver, model 2400T/2400R (Noraxon Inc, Scottsdale, Arizona). A self-adhesive dual Ag/AgCl electrode (Noraxon Inc) was placed on the palpated belly of the biceps brachii in parallel with the muscle fibers at the midportion of the muscle. To reduce interelectrode impedance, resistance caused by dead skin cells, skin oil, and moisture,[2] the skin was cleaned using antimicrobial wipes before application. The sEMG signals were preamplified (×500) near the electrodes and were band pass filtered between 10 and 500 Hz and sampled at a rate of 1200 Hz.

An unlimited amount of time was allotted for each pitcher to perform her normal warm-up routine before the initiation of the test. To determine the maximal amount of muscle activity in each subject's biceps, a 3- to 5-second maximal manual muscle test (MMT) with maximal isometric elbow flexion with the forearm in supination against a fixed flat surface and the elbow flexed at 90° was performed. Three consecutive trials with 3 seconds between each were recorded. The 3- to 5-second interval with the highest sEMG activity was selected as the maximal MMT representing 100% biceps muscle activity (100% MMT)[14] and was used to normalize the biceps activity within each pitcher.

Once the maximal biceps muscle activity was recorded via sEMG and the motion analysis test commenced, the subjects were asked to throw a number of warm-up pitches until they felt at ease with the equipment. The subjects threw into a strike zone net 8.3 m from a distinct pitching location, in comparison with the fast-pitch softball mound-to-plate distance of 12.2 m.[18] Six 5-second trials were obtained for each subject: 3 fastball windmill pitches and 3 overhand throws. All of the pitchers were familiar with the overhand throwing mechanics and practiced numerous overhand throws into the simulated strike zone.

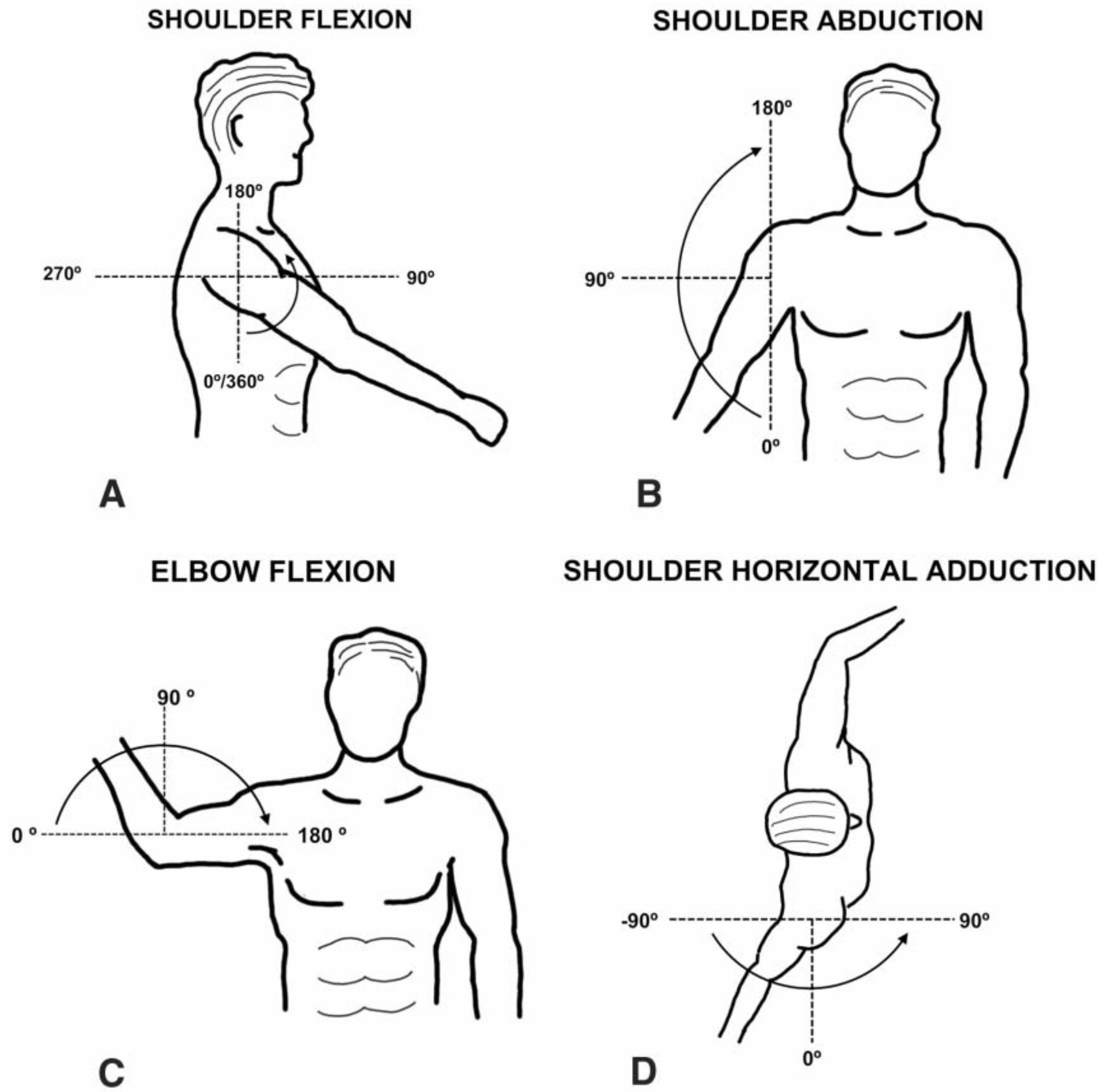

Figure 3. The angle conventions for the parameters: A, shoulder flexion; B, shoulder abduction; C, elbow flexion; D, shoulder horizontal adduction. Adapted from Escamilla et al.[4]

Each marker motion capture trial was matched using previously established softball[14] and baseball[6] pitching phases to quantify each phase per analyzed trial for every subject. The windmill pitch was phased based on the positions of the clock as described in Table 1 and depicted in Figure 1. For the overhand throw, the subjects' throwing kinematics were matched as closely as possible to the baseball pitching phases described in Table 2 and depicted in Figure 2.

The pitching motion analysis, sEMG activity, and ball velocity data were collected simultaneously for all 6 trials. From the trials, 1 fastball windmill pitch and 1 overhand throw, with the best matching and maximum ball velocities as recorded on the radar gun, were selected for analysis. The pitchers reported that all of the ball velocities were within their normal range, and minimum variability (averaged coefficient of variance, 1.4%) was seen within the trials. The raw sEMG signals for each subject were rectified and the root-mean-square calculated.[3] The data were normalized to the subject's 100% MMT. The maximum percentage MMT from the 2 selected trials was calculated for each phase and for each pitcher. The muscle activation for each phase of the fastball windmill pitching and the overhand throwing was averaged from the entire group of pitchers and presented as means along with SDs. Kinematic parameters were measured and calculated using the motion analysis software—planar analysis of the lateral humeral epicondyle and styloid process of the radius angular displacements was conducted with respect to a fixed referenced frame in the iliac crest and the greater tuberosity. Shoulder flexion, shoulder abduction, elbow flexion, and elbow angular velocity parameters were measured for the windmill pitch. Shoulder horizontal adduction and shoulder abduction parameters were measured for the overhand throw.

The angle conventions for the parameters are depicted in Figure 3.

The data were analyzed to determine biceps activity and peak activity areas during each phase of the windmill pitch and the overhand throw. A Friedman test was then performed to determine if a significant difference existed between the mean percentage MMT of the fastball windmill pitch and the overhand throw using statistical software (SPSS Inc, Chicago, Illinois).

RESULTS

The mean ball velocity at release during the fastball windmill pitch was 23.9 ± 2.2 m/s and during the overhand throw 23.9 ± 3.2 m/s, and these were not statistically different (P = .71). The maximum biceps brachii muscle activation during the overhand throw (19% ± 11% MMT) was significantly lower than during the windmill pitch (38% ± 16% MMT; P = .02).

The maximum biceps activity consistently occurred during phase 5 (38% ± 16% MMT), the 9-o'clock phase of the windmill pitch, in which the elbow joint extended to 26° ± 8° of flexion, representing the minimum flexion angle (Figures 4A and 5C). The second highest activity occurred during phase 6 (36% ± 17% MMT), corresponding to the follow-through position of the windmill cycle (Figure 4A). The biceps activity during phase 6 was significantly lower than during phase 5 (P = .01). In comparison, the overhand throw had the maximum biceps activity occur during phase 3 (19% ± 11% MMT), arm cocking, during which the elbow reached its maximum flexion angle. This was slightly different from the second highest muscle activation, which occurred during both phase 4 (18% ± 12% MMT) and 5 (18% ± 12% MMT), arm acceleration and deceleration, respectively (Figure 4B). The biceps activity during phases 4 and 5 was significantly higher than during phase 6, follow-through (P = .01).

Maximum shoulder abduction angles during windmill pitching (156° ± 18°) occurred during the 12-o'clock position of the arm (phase 3) (Figure 5B). During the 9-o'clock position of the arm (phase 5), the pitchers experienced maximum shoulder flexion at an angle of 291° ± 10° (Figure 5A). The pitching mechanics among all 7 pitchers varied within the windup position (phase 1) and the beginning of the 6-o'clock position (phase 2); however, the pitching motion was consistent throughout the remainder of the cycle. As mentioned previously, the minimum elbow flexion occurred during the 9-o'clock position of the arm (phase 5) at an angle of 26° ± 8°. During this phase, the elbow extended at a maximum angular velocity of 1264 ± 436 deg/s (Figure 5D). Ball release occurred at a mean 10° ± 7° and 15° ± 70° of shoulder flexion and abduction angles, respectively. A mean elbow flexion angle of 28° ± 5° and mean angular velocity of 302 ± 88 deg/s were also apparent at ball release through the windmill pitch.

During the overhand throw, maximum shoulder horizontal adduction angles (–33° ± 9°) took place during arm acceleration (phase 4). Maximum shoulder abduction angles (108° ± 27°) and maximum elbow flexion occurred during arm cocking (phase 3), as also reported by Fleisig et al.[5] Ball release occurred at a mean 5° ± 3° and 73° ± 37° of shoulder horizontal adduction and shoulder abduction angles, respectively.

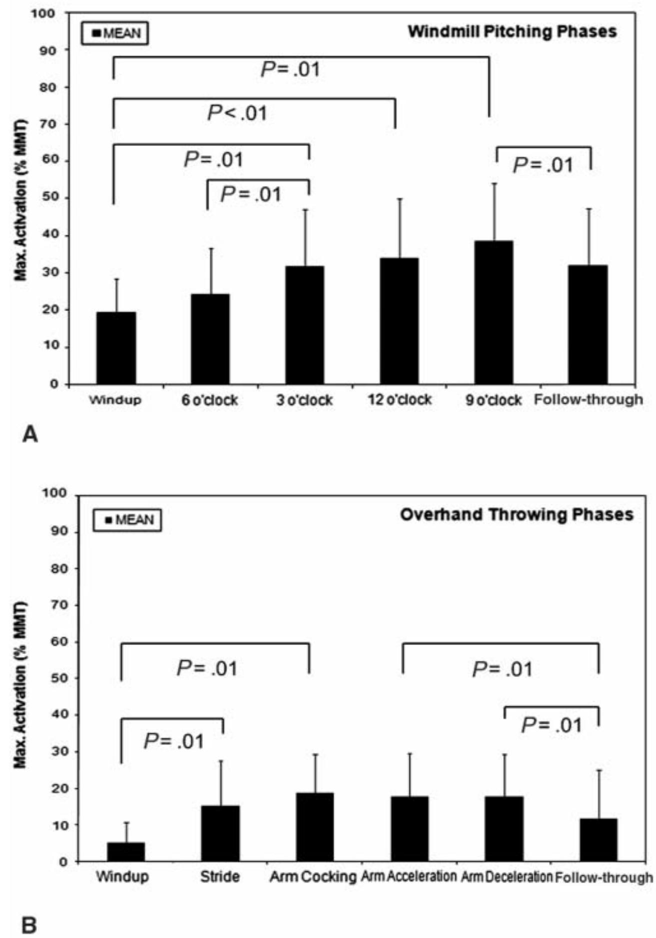

Figure 4. Biceps brachii maximum muscle activation (percentage maximal manual muscle test [MMT]) during windmill pitching phases (A) and overhand throwing phases (B).

DISCUSSION

This study presented an electromyographic analysis of the biceps brachii at different phases of the fastball windmill pitching and the overhand throwing motion. The highest biceps brachii activity was measured during the fifth phase of the windmill pitch, from 9 o'clock to ball release. The highest reduction of elbow angular velocity was apparent during this phase, in which the highest level of biceps eccentric contraction is most likely to occur. This finding supplements other biomechanical studies on the windmill pitch that indicate that shoulder distraction stress and elbow extension torque are highest just before ball release.[1,17] After release, continued biceps activity may act primarily to assist in prevention of further shoulder distraction.

A second finding of this study is that fastball windmill pitching has a significantly higher degree of peak biceps motor activation than does overhand throwing (38% vs 19% MMT), supporting our initial hypothesis. As stated by

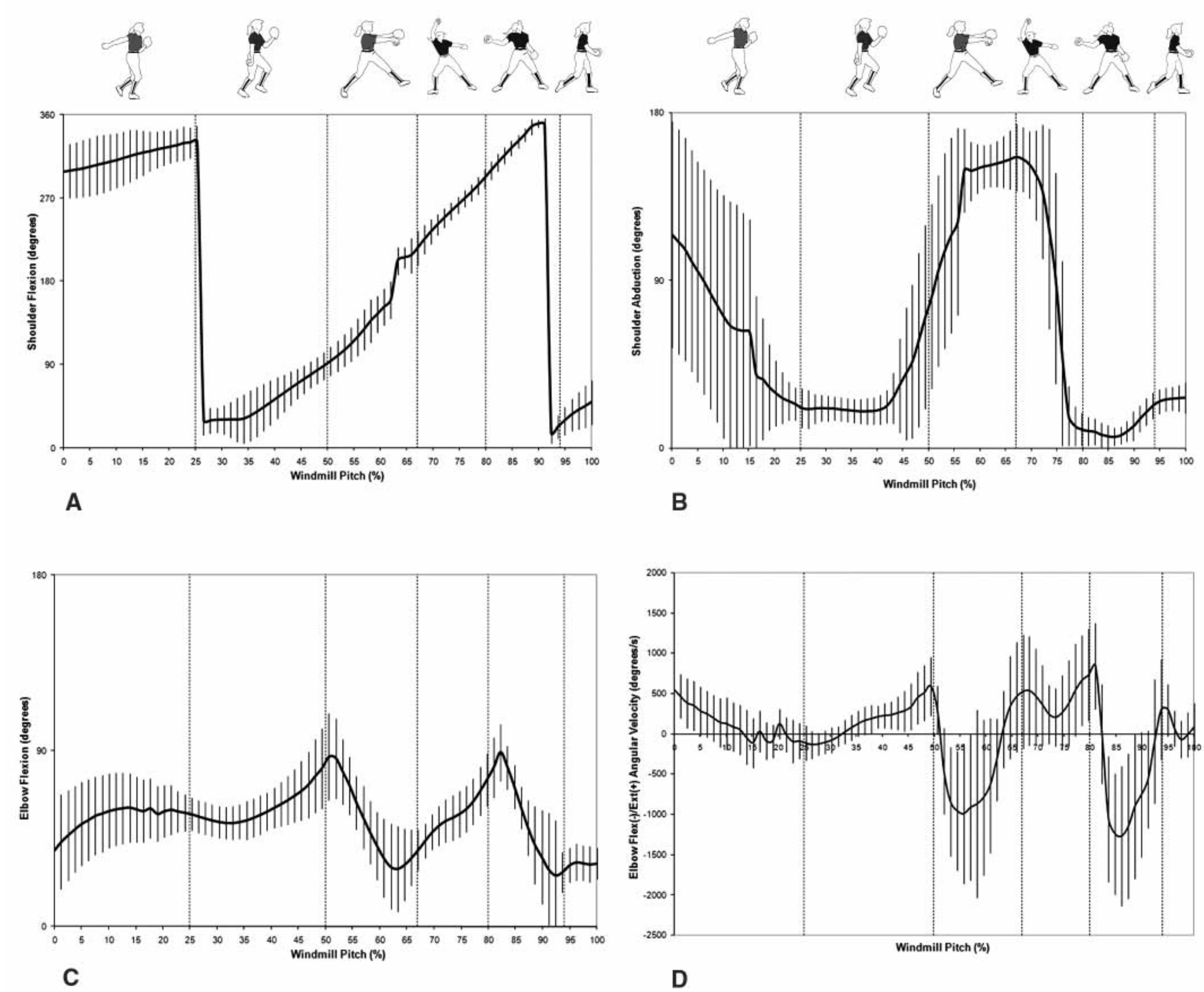

Figure 5. A, shoulder flexion. B, shoulder abduction. C, elbow flexion. D, elbow angular velocity versus percentage windmill pitch. Mean and SD data for all pitchers are represented in the graphs.

Gowan et al,[9] overhand throwing requires the biceps brachii to provide elbow flexion torque and aid in resisting shoulder distraction. In their study, the highest biceps activity occurred during the arm cocking stage (28% MMT) among professional baseball pitchers. We found increased activity during the same phase among the softball pitchers tested here (19% MMT). The muscle activity during the other phases of the baseball pitch ranged from 12% to 17% MMT, compared with a range of 5% to 18% MMT during the overhand throw among the softball pitchers in this study. However, during the windmill pitch, the biceps brachii muscle activity was much higher during most of the phases and ranged from 20% to 34% MMT.

Interestingly, the deceleration phase in overhand throwing, not the arm cocking phase, has been recognized as the most violent of phases.[15] It has been noted that during this phase, the extending elbow joint is decelerated, causing eccentric muscle activity of the biceps brachii. Our finding that biceps activation is higher in the windmill pitching motion, specifically during the 9-o'clock position of the arm (phase 5) in which maximum deceleration and maximum elbow extension occur, indicates that windmill pitchers may be at increased risk for developing overuse biceps throwing injuries versus overhand throwers because of the increased eccentric contraction of the biceps.

In the care of our local professional softball team, we have found that anterior shoulder pain is a common complaint and common cause of lost time from pitching among elite fast-pitch windmill pitchers. Of 5 available pitchers, 3 missed time from pitching during the season because of anterior shoulder pain. In addition, 1 pitcher had a rupture of the long head of the biceps tendon requiring operative biceps tendinitis. In this case, the patient had 1 month of anterior shoulder pain complaints before a traumatic rupture of the tendon during a single pitch. Using physical examination, we have found that this anterior shoulder pain is often localized to the biceps groove, potentially implicating the long head biceps tendon as a potential source of the symptoms. The mechanism of this injury remains unclear. The findings of this study suggest that increased eccentric biceps activity may be a potential contributing factor.

In addition, we have noted that overall shoulder motion is greater during the windmill pitch than during an overhand throw. Windmill pitchers swing their arms 360°—a maximum of 156° of shoulder abduction was seen during the windmill pitch, compared with a maximum of 108° during the overhand throw among the pitchers. This increased movement may result in increased tendon excursion through the bicipital groove, which is a second potential cause of tendon injury.

Our findings are similar to the conclusion of other studies that have analyzed common shoulder injuries among female softball pitchers.[1,13] Understanding of the biceps muscle activity in fast-pitch softball may help physicians, physical therapists, and athletic trainers use better rehabilitative measures for patients with anterior shoulder pain. A basic understanding of the phases in the throwing cycle and muscles at work during each position allows for a better grasp of the mechanisms of injury. Although it is unlikely the basic throwing motions can be altered, early identification of the problem with early intervention may minimize time lost for competition. Furthermore, in patients with anterior shoulder pain that appears clinically attributable to biceps injury, throwing motion analysis may be helpful to address elbow flexion and potentially forearm rotation to determine any differences that may place the pitcher at risk for biceps-related lesions.

It is difficult to make accurate comparisons between windmill and overhand pitching because of the very different pitching motions. Therefore, some limitations were apparent owing to these differences, and a study design that involved an overhand throw instead of an overhand pitch was chosen. An overhand pitch would have been invalid as these players do not routinely perform this motion. Fast-pitch softball pitchers throw with an underhand motion far more often than they do overhand; however, if they are not pitching (ie, throwing to first base), they use overhand throws exclusively and are well experienced with overhand throwing mechanics, as evidenced by near-equal release velocities in both underhand and overhand throws. Second, although several studies have already investigated biceps activity in male baseball pitchers,[5,9,15] a comparison between male baseball and female softball pitchers would introduce a significant potential source of gender bias. However, as shown above, we arrived at similar conclusions compared with those reported in the literature from baseball pitchers.

Other limitations of this study included the use of sEMG to evaluate overall biceps muscle activity and having the pitchers throw in a biomechanics laboratory setting. It was impossible to differentiate activity of the long head versus the short head, and the motions performed involved both shoulder and elbow function. Therefore, it was not possible to tell if biceps activity was occurring as a function of shoulder or elbow motion based on the data collected. Also, the laboratory setting limited the distance between the strike zone net and the pitching location. However, there was only a 3.9-m difference between our laboratory setup and the fast-pitch softball mound-to-plate regulation distance. Furthermore, the subjects were asked to throw as if in a real game situation. Ball velocities similar to real pitching speeds were achieved, therefore making the results found in the study applicable.

CONCLUSION

This study demonstrates that the biceps brachii muscle is most active during the 9-o'clock and follow-through positions of the windmill pitch, in which maximum elbow extension occurs and the highest amount of eccentric contraction is expected, causing the biceps to act as a braking mechanism. The total biceps activity during the windmill pitch is higher than with an overhand throw of similar ball release velocity. The differences between the overhand throw and windmill pitch biceps brachii activity and repetitive eccentric contractions may explain the potential for biceps problems in softball. Injury prevention mechanisms should focus on the phases with highest muscle activity, including the windmill pitch release.

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