# Biceps Tendon Changes and Pitching Mechanics in Youth Softball Pitchers

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Key words
injury, ultrasound, windmill softball pitching

**accepted** 03.08.2020
**published online** 18.09.2020

Bibliography
Int J Sports Med 2021; 41: 277–282
**DOI** 10.1055/a-1236-3855
**ISSN** 0172-4622

Georg Thieme Verlag KG, Rüdigerstraße 14, 70469 Stuttgart, Germany

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**ABSTRACT**

With the lack of pitch count regulation, youth softball pitchers are experiencing unremitting high stresses on the anterior shoulder. The purpose of this study was to examine the association of acute changes in the long head of the biceps tendon with pitching kinematics and kinetics in youth softball pitchers following an acute bout of pitching. Twenty-three softball pitchers (12.17 ± 1.50 yrs.; 160.32 ± 9.41 cm; 60.40 ± 15.97 kg) participated. To investigate the association between biceps tendon changes and kinematic and kinetic changes from pre- to post-simulated game, each biceps tendon measure was split into those whose biceps tendon thickness, width, and/or area increased pre- to post-simulated game, and those whose did not. There were significant differences in biceps tendon longitudinal thickness ($Z = -2.739$, $p = 0.006$) and pitch speed; as well as a difference between groups in biceps tendon transverse thickness and the amount of change in trunk rotation at the start of the pitching motion ($p = 0.017$) and the amount of change in trunk flexion at ball release ($p = 0.030$). This study illustrates the association of trunk and lower extremity kinematics and shoulder kinetics with morphologic changes in the biceps tendon with an acute bout of windmill softball pitching.

## Introduction

Youth softball involves year-round participation with a high volume of play; and inherently exposes the throwing arm to high levels of stress. Recently there has been more attention to the reported pain and fatigue experienced by youth softball pitchers [1, 2]. Comparing the sports of baseball and softball, overuse injury rates and patterns are similar [3–7], with some reports of higher overuse injury in softball [5, 8]. The upper extremity, namely the throwing shoulder in windmill softball pitchers, is the most frequently injured part of the body [2, 9–13], with many injuries to softball players being a result of overuse [14]. Specifically, anterior shoulder pain is a regular complaint, most likely a result of the windmill pitching motion in softball [15].

The mechanics of the softball pitch place a great demand on the long head of the biceps tendon (LHBT) during both the acceleration and follow-through phases of the pitch [16, 17]. The biceps-labral complex must work to resist high shoulder distraction forces present during these phases of the pitch. The high force loads placed on the LHBT, and the repetitive nature of the windmill pitching motion utilized in softball, is a potential culprit of the reported shoulder pain and pathologic changes [15, 18, 19]. Also, due to the large range of motion required of the pitching shoulder; the large excursion of the LHBT can further pose increased injury susceptibility [16, 17]. The anatomy of the LHBT has been well-established and authors have theorized anatomic reasons for the pathologic processes producing tendinopathy and a spontaneous risk of injury [20, 21]. However, the demands of the windmill pitch and the pathologic processes it may produce on the LHBT is lacking within the literature.

Within the sport of baseball, performance metrics have been examined in attempt to mitigate injury susceptibility in youth pitchers, including number of pitches thrown, innings pitched, and rest days [22]. Unlike baseball, softball does not have an official workload recommendation; however, some teams anecdotally attempt to quantify and limit pitch count and workload. Since both sports require proximal to distal sequencing within an open kinetic chain, and injury prevention measures have not thoroughly been investigated within the sport of softball, further investigation into not only workload but also anterior shoulder forces over an extended workload is necessary.

With the increased awareness of injury susceptibility in softball, there has been a shift in focus to examining associations between the prevalence of pain and pitching mechanics [23, 24]. It has been found that those pitching with upper extremity pain have altered pitching mechanics compared to those pitching without pain [23]. Similarly, the association of an increased stride length and a posteriorly shifted center of mass (COM) with those experiencing upper extremity pain has been established in collegiate pitchers [23, 24]. However, to the authors' knowledge, there are no known studies examining pain and pitching mechanics in youth softball athletes. With the increased awareness of pain and fatigue in youth softball pitchers [1–3, 25–27], as well as the lack of established sanctions of pitch count regulations, consecutive innings and/or games pitched, or required rest days, greater investigation into youth pitching and the acute biomechanical changes that occur following a pitching performance is needed. Previously, the examination of the LHBT in youth revealed significant increases in longitudinal and transverse thickness following an acute bout of pitching. These dimensional increases were hypothesized to be an acute inflammatory response [28] which emphasizes the stress that the LHBT endures over the duration of a game. While research has not yet determined the specific cause of LHBT inflammation during a pitching bout, there is reason to believe that mechanics, especially those surrounding the trunk and upper extremity, may impact the degree of change in LHBT measures. Specifically, certain pitch mechanics may elicit a greater inflammatory response than others, which may cause more undue harm and shoulder pain. With pitchers already displaying high rates of shoulder pain, it is pertinent to understand how mechanics may exacerbate the stress at the shoulder, which is currently believed to cause shoulder pain.

Therefore, it was the purpose of this study to examine the association of acute changes in the LHBT, with pitching kinematics and kinetics in youth softball pitchers following an acute bout of pitching. Specifically, we investigated the association of LHBT changes (longitudinal thickness, transverse thickness, transverse width, and transverse area) with trunk kinematics (flexion, lateral flexion, and rotation), COM (in relation to base of support), stride length (height normalized), and shoulder kinetics (abduction/adduction moment; internal/external moment, and flexion/extension moment) prior to and immediately following a simulated game protocol. It was hypothesized that LHBT thickness (longitudinal and transverse), width (transverse), and area (transverse) would increase following the simulated game when compared to pre-simulated game measurements. It was also hypothesized that the aforementioned increase would be associated with altered pitching kinematics (trunk, COM, and stride length) and increased shoulder kinetics (abduction/adduction moment; internal/external moment, and flexion/extension moment) between the first and last inning of a simulated game.

## Materials and Methods

Twenty-three female youth softball pitchers (12.17 ± 1.50 yrs.; 160.32 ± 9.41 cm; 60.40 ± 15.97 kg) volunteered to participate. Inclusion criterion required the participants to be actively competing on a team's roster as a pitcher. Additionally, they had to be surgery and injury-free for the past six months. Injury was defined as being diagnosed by a physician or athletic trainer resulting in time loss from practice or competition. The Institutional Review Board of Auburn University approved all testing protocols and informed written consent was obtained from each participant prior to participation.[29] Participants were instructed on the LHBT imaging and simulated game protocol. A NextGen LOGIQe Ultrasound (GE Healthcare, Milwaukee, WI, USA) using a 4–12 MHz linear array transducer in B-mode was used for LHBT image collection. Acquisition parameters were constant for all participants and included a 10 MHz frequency, 3.5 cm depth, and one transmit focus point [28].

Each participant had dominant arm LHBT ultrasound imaging prior to and immediately following the simulated game protocol. Ultrasound data were collected using previously established methods [28, 30]. The participant was seated with elbow flexed, forearm supinated, and wrist in neutral resting on the contralateral knee. The investigator placed the probe on the anterior aspect of the shoulder on the LHBT, perpendicular to the humerus. All measurements were taken at the widest qualitatively identifiable aspect of the LHBT. Transverse and longitudinal views were recorded as single images. The transverse view was used to locate the bicipital groove through the identification of the greater and lesser tuberosity. Once the bicipital groove was determined, an image of the LHBT was recorded. The probe was then turned 90°, while remaining at the same level of the transverse view, to record the longitudinal view [28, 30]. The investigator marked a small dot on the skin at the lateral border of the transducer to identify the bicipital groove. This procedure was repeated three times and the mean of the three measurements was used for analysis.

Two investigators performed all ultrasound measurements. Intra-rater reliability was determined during a pilot study of 5 participants. Measurements of transverse width, transverse thickness, and longitudinal thickness were performed using the diameter function on the ultrasound machine. Transverse area was measured by tracing the tendon with the ultrasound trackball. The investigators reported excellent intra-rater reliability using the techniques previously described, with an ICC(3,k) of 0.90–0.98 for all measurements. Standard error of measurement (SEM = pooled standard deviation × $\sqrt{1\text{-ICC}}$) and the minimal detectable change at the 90 % confidence interval ($MDC_{90}$ = SEM × $\sqrt{2}$ × 1.65) for transverse width, transverse thickness, and longitudinal thickness were also calculated from the pilot data. For the data to indicate a significant change not related to measurement error, observed differences had to exceed the MDC. Longitudinal thickness $MDC_{90}$ was

 

0.024 cm, transverse width $MDC_{90}$ was 0.014 cm, transverse thickness $MDC_{90}$ was 0.029 cm, and transverse area $MDC_{90}$ was 0.019.

Kinematic data were collected at 240 Hz using an electromagnetic tracking system (trackSTAR™, Ascension Technologies, Inc., Burlington, VT, USA) synced with Biomechanics Analysis Software (The MotionMonitor, Innovative Sports Training, Chicago, IL, USA). Eleven electromagnetic sensors were attached to the participants using previously established methodologies [31]. A linked segment model was developed using the digitized joint centers for ankle, knee, T12-L1, and C7-T1 by the digitized medial and lateral aspect of each joint, then calculating the midpoint between those two points [32–35]. Hip and shoulder joint centers were estimated by means of a previously established rotation method [36, 37]. The world axis was represented with the positive Y-axis in the vertical direction; anterior to the Y-axis and in the direction of movement was the positive X-axis; and orthogonal and to the right of X and Y was the positive Z-axis. Raw data regarding sensor positioning and orientation were transferred to a locally based coordinate system. Euler angle sequences consistent with the International Society of Biomechanics standards and joint conventions were used to define position and orientation of the body segments [34, 35]. The trunk was modeled relative to the world axis, using the Euler sequence of ZX'Y", while the YX'Y" sequence was used for shoulder motion relative to the trunk. All raw data were independently filtered along each global axis using a $4^{th}$-order Butterworth filter with a cut off frequency of 13.4 Hz [32, 33, 38].

Once all kinematic sensors were secured, participants were given an unlimited time to perform their own specified pre-competition warm-up (average warm-up time was 7 minutes). Participants were instructed to throw their desired pitches (fastball and change-up) based on randomly provided game situations. An expert with seven years of youth, high school, and collegiate coaching experience developed the game situation protocol [39, 40]. The investigator provided verbal feedback of hitter counts (balls and strikes), simulated at-bat outcomes (base hit, base on balls, hit-by-pitch, ground-outs, and fly-outs), and simulated runners. Participants were required to produce three outs an inning as per the standard rules of softball. After three outs were recorded, a rest period was provided to simulate the second half of the inning. In attempt to mimic typical offensive innings in youth softball, rest periods were randomly altered in length from 7 to 14 minutes. Pitch count was limited to the participant's average pitch count during competition. Average pitch count for the simulated game was 61 ± 7 pitches. It should be noted that though the participants threw a simulated game, no fatigue measures were assessed. Three fastballs in the first inning and three fastballs in the last inning were recorded, averaged, and used for analysis. The pitching motion was broken into five different events; Start of pitching motion, top of pitch foot contact (FC), ball release (BR), and follow-through. All kinematic and kinetic variables were analyzed at each of the five pitching events.

Kinematic data were normally distributed, therefore a 2 (time) x 5 (event) repeated measures multiple analysis of variance (MANOVA) was used to investigate if there were any significant differences in kinematics between the first and last inning of the simulated game at the five pitching events. Ultrasound and kinetic data were non-normally distributed therefore the Wilcoxon Signed Rank test was used to determine any significant differences between the first and last inning. A Bonferroni adjustment was used to limit type 1 error. For ultrasound data the p value was set at 0.0125 and for kinetic data the p value was set at 0.0167. A paired samples t-test with a p value set to 0.05 was used to determine if there was a significant difference in pitch speed between the first and last inning of the simulated game. To investigate the association between LHBT changes and kinematic and kinetic changes from pre- to post-simulated game, each LHBT measure was split into two groups: those whose LHBT thickness, width, and/or area increased pre- to post-simulated game, and those whose did not. Likewise, investigators calculated the change in kinematic and kinetic measures by subtracting the last inning from the first inning. One-way MANOVAs with a p value set to 0.05 were run for each LHBT variable (longitudinal thickness, transverse thickness, transverse width, and transverse area) to investigate group differences in kinematic variables between those whose LHBT measures increased and those whose LHBT measures decreased. Due to non-normally distributed kinetic data, a Kruskal-Wallis test, with a p value set to 0.0167 was ran for each LHBT variable (longitudinal thickness, transverse thickness, transverse width, and transverse area) to investigate if there were any group differences between bicep tendon change and the amount of change for each kinetic variable.

# Results

## Comparison of kinematic, kinetic, and ultrasound measures pre and post simulated game

There were no statistically significant differences in kinematics or kinetics between the first and last inning at any of the pitching events (▶ **Tables 1**–**2**). However, examining the LHBT there was a statistically significant increase in LHBT longitudinal thickness pre- and post-simulated game ($Z = -2.739$, $p = 0.006$) (▶ **Table 3**), as well as a statistically significant decrease ($p < 0.01$) in pitch speed from the first to last inning of the simulated game (pre: 46 mph, post: 45 mph) (▶ **Table 4**).

## Comparisons of the amount of change in kinematic, kinetic, and ultrasound measures from pre to post simulated game

There were statistically significant differences in groups for LHBT transverse thickness and the amount of change in trunk rotation at the start of the pitching motion ($p = 0.017$) and the amount of change in trunk flexion at BR ($p = 0.030$). Specifically, those who had an increase in LHBT transverse thickness had significantly less change in trunk rotational position at the start of the pitching motion (pre: 19.60°, post: 18.64°, change: –0.96°) than those whose LHBT transverse thickness did not increase (pre: 29.45°, post: 15.92°, change: –13.53°). For trunk flexion at BR, those whose biceps tendon transverse thickness increased (pre: 3.47°, post: 1.10°, change: –2.37°) displayed a significantly different change in trunk flexion at BR than those whose LHBT transverse thickness decreased (pre: 4.07°, post: 5.76°, change: 1.69). Specifically, those whose LHBT transverse thickness increased had a decrease in trunk flexion at BR while those whose LHBT transverse thickness decreased had an increase in trunk flexion at BR (▶ **Table 5**). There

  

▶ **Table 1** Kinematic variable mean (standard deviation) from the 1st and last inning of the simulated at each pitching event.

| Variable | Pre | Post |
|---|---|---|
| **Start of Pitching Motion** | | |
| Stride Length (% height) | 1.10 (0.18) | 1.09 (0.19) |
| Trunk Flexion (°) | 5.44 (12.38) | 5.79 (11.54) |
| Trunk Rotation(°) | 23.03 (16.12) | 17.70 (15.46) |
| Trunk Lateral Flexion(°) | 2.33 (9.15) | 1.96 (8.67) |
| COM (%) | 38.55 (11.76) | 39.47 (13.71) |
| **Top of Pitch** | | |
| Stride Length (% height) | 0.97 (0.16) | 0.98 (0.18) |
| Trunk Flexion (°) | 0.05 (11.38) | 0.39 (12.29) |
| Trunk Rotation (°) | 59.84 (13.82) | 58.28 (16.94) |
| Trunk Lateral Flexion (°) | 0.30 (12.62) | 1.54 (11.60) |
| COM (%) | 43.68 (8.63) | 44.25 (10.16) |
| **Foot Contact** | | |
| Stride Length (% height) | 0.89 (0.13) | 0.88 (0.15) |
| Trunk Flexion (°) | 7.29 (13.16) | 7.01 (14.03) |
| Trunk Rotation (°) | 69.34 (13.57) | 68.86 (14.70) |
| Trunk Lateral Flexion (°) | 4.82 (11.40) | 3.41 (11.40) |
| COM (%) | 47.06 (6.72) | 47.12 (7.57) |
| **Ball Release** | | |
| Stride Length (% height) | 0.69 (0.12) | 0.67 (0.12) |
| Trunk Flexion (°) | 3.68 (9.33) | 2.72 (10.65) |
| Trunk Rotation (°) | 36.23 (12.42) | 35.34 (12.54) |
| Trunk Lateral Flexion (°) | 12.99 (11.0) | 13.47 (10.87) |
| COM (%) | 48.19 (10.03) | 48.68 (11.12) |
| **Follow-Through** | | |
| Stride Length (% height) | 0.62 (0.10) | 0.60 (0.13) |
| Trunk Flexion (°) | 1.70 (9.51) | 2.13 (10.10) |
| Trunk Rotation (°) | 17.32 (15.16) | 17.29 (14.17) |
| Trunk Lateral Flexion (°) | 9.20 (9.43) | 8.98 (9.70) |
| COM (%) | 47.02 (12.94) | 47.60 (13.94) |

Note: **Stride length:** % height; **trunk flexion:** (–) flexion, (+) extension; **trunk rotation:** (+) rotation towards pitching arm side, (–) rotation towards glove arm side; **trunk lateral flexion:** (–) flexion towards the pitching arm side, (+) flexion towards the glove arm side; **COM:** 0% representing COM entirely over the drive leg and 100% representing COM entirely over the stride leg.

▶ **Table 2** Maximum and minimum shoulder kinetics from the 1st and last inning of a simulated game.

| Maximum Kinetics | Pre (Nm/kg) | Post (Nm/kg) |
|---|---|---|
| Abduction/Adduction Shoulder Moment | 2.41 (2.28) | 2.31 (2.23) |
| Internal/External Shoulder Moment | 1.03 (0.69) | 1.35 (2.27) |
| Flexion/Extension Shoulder Moment | 2.48 (1.92) | 2.74 (2.18) |
| **Minimum Kinetics** | **Pre (Nm/kg)** | **Post (Nm/kg)** |
| Abduction/Adduction Shoulder Moment | −2.47 (1.84) | −2.32 (1.93) |
| Internal/External Shoulder Moment | −0.85 (0.97) | −1.16 (2.13) |
| Flexion/Extension Shoulder Moment | −2.40 (2.29) | −2.36 (2.51) |

▶ **Table 3** Long head of the biceps tendon mean (standard deviation).

| Ultrasound | Pre | Post |
|---|---|---|
| Transverse Width | 0.66 (0.23) | 0.67 (0.18) |
| Transverse Thickness | 0.44 (0.12) | 0.44 (0.12) |
| Longitudinal Thickness * | 0.39 (0.07) | 0.43 (0.08) |
| Transverse Area | 0.23 (0.12) | 0.23 (0.09) |

Note: * denotes significant difference at $p < 0.0125$.

▶ **Table 4** Pitch speed in the 1st and last inning of the simulated game.

| | 1st Inning | Last Inning | P value |
|---|---|---|---|
| **Pitch Speed** | 46 mph | 45 mph | <0.001 * |

Note: * denotes significant difference at $p < 0.05$.

▶ **Table 5** Significant kinematic differences between groups for LHBT transverse thickness changes.

| Variable | Pre | Post | Change |
|---|---|---|---|
| Decreased Transverse Thickness | | | |
| Trunk Rotation at start of pitching motion | 29.45 | 15.92 | −13.53 |
| Trunk Flexion at ball release | 4.07 | 5.76 | +1.69 |
| Increased Transverse Thickness | | | |
| Trunk Rotation at start of pitching motion | 19.60 | 18.64 | −0.96 |
| Trunk Flexion at ball release | 3.47 | 1.10 | −2.37 |

Note: All values presented as means. A negative change indicates a decrease in value, whereas a positive change indicates an increase in value.

were no statically significant differences between groups for any biceps tendon measurement and kinetic variable.

## Discussion

The most important findings of this study were an increase in LHBT longitudinal thickness after a simulated game, a decrease in pitch speed from the first to last inning, and a difference in groups for LHBT transverse thickness and the amount of change in trunk rotation at the start of the pitching motion and the amount of change in trunk flexion at BR. These findings are in agreement with previous work examining the LHBT in youth baseball, softball, and wheel chair basketball athletes, which concluded biceps tendon changes were a result of the activity, and duration of the activity [28, 41, 42]. Additionally, this study was also able to establish kinematic relationships between the pitching motion and changes in the LHBT, specifically changes in transverse thickness. To the authors' knowledge, this is the first report of the association of LHBT changes and pitching mechanics in youth softball pitchers.

The current study revealed differences in trunk rotation, at the start of the pitching motion and at BR, between those who displayed increased LHBT transverse thickness and those whose LHBT transverse thickness decreased. Specifically, those whose LHBT transverse thickness decreased displayed less trunk rotation towards the pitching arm the end of the simulated game than at the beginning. Additionally, the finding of less change in trunk rotation at the start of the pitching motion from the first inning to the last inning and those with increased LHBT transverse thickness change is interesting. The lack of positional trunk rotation differences associated with LHBT changes deserves greater investigation. Additionally it should be noted that in an examination of collegiate softball pitchers, it was found that those who were experiencing upper extremity pain displayed greater shoulder horizontal abduction at FC in the change-up pitch than those pitchers without upper extremity pain [23]. Though shoulder horizontal abduction was not analyzed in the current paper, understanding positional data of shoulder horizontal abduction as well as LHBT measures could prove beneficial. The line of pull of the LHBT is dependent upon the position of the humerus relative to the shoulder as the biceps is attempting to contract. Thus, a position of exaggerated or greater shoulder horizontal abduction could predispose undue stress upon the LHBT within the windmill softball pitching motion. Additionally, when shoulder horizontal abduction is examined, it is relative to the trunk positioning. Therefore, LHBT thickness alterations corresponding trunk positioning are plausible as it has also been reported that trunk rotation positions within the windmill softball pitch are associated with upper extremity pain [24]. Specifically, pitchers with upper extremity pain revealed increased trunk rotation towards the throwing arm side at FC [24]. Hence, it could be postulated that the optimal degree of trunk rotation will vary based on specific points in the pitching motion. Rotating out of this "optimal range", whether having too little or too much trunk rotation, may increase injury susceptibility, and increase the demand placed on the LHBT.

There are currently no studies to the authors' knowledge linking trunk flexion and pain. Thus, the current finding of decreased trunk flexion at BR throughout the simulated game for those whose LHBT transverse thickness increased; compared to those who increased trunk flexion throughout the simulated game for those whose LHBT transverse thickness decreased is important. While the amount of change between time points is small and may not be clinically significant, results of trunk flexion changes trending in opposite directions requires further research. The increase in LHBT transverse thickness associated with decreased trunk flexion may be a result of increased forces on the shoulder due to decreased core usage and stability throughout the pitch. Research shows that compensations proximally along the kinetic chain may place the shoulder at increased risk of injury, as the glenohumeral structures are exposed to increased demands due to proximal insufficiency [43–46]. This increased stress placed upon the shoulder may be the mechanism leading to increased LHBT transverse thickness.

This study has implications for softball pitchers and their athletic health, especially as number of innings increase and playing season and career progresses. Although these changes in kinematics associated with LHBT measures are small, a coach can depict when they begin to see a pitcher increase or decrease trunk flexion at BR and can similarly identify changes in trunk rotation. With decreased trunk flexion being associated with increased biceps tendon measures, it is reasonable to assume these changes may together be an indicator of fatigue. Previous work has associated increased game exposure to fatigue and pain [1], thus these indications of fatigue, may be linked to increased trauma and injury susceptibility for the pitcher's throwing arm LHBT.

The major limitation of this study includes not assessing fatigue. While the current study used a pitch count considered average for individuals in this age range, varying degrees of ability and individual resistance to fatigue can limit the generalizability of a simulated game eliciting true fatigue. Within the youth age range, there is normally a large range in levels of endurance and strength, therefore the average pitch count used may be able to provoke fatigue in some pitchers, and not others. Additionally, some reports have acknowledged pitch count can reach as high 191 pitches in a single day tournament [1]. Therefore, fatigue experienced during a tournament will vary greatly from a single game exposure. As a result, our single game effort data associated with LHBT changes should be alarming when compared to tournament play and pitchers throwing multiple games within a day. Future research should look to examine multiple game exposures to investigate the effect of tournament play on pitcher kinematic, kinetics and LHBT measures. While the same investigator did perform pre and post LHBT measurements, which is a strength, they were not blinded to the time points which may have induced some bias. This potential of bias is a limitation of the current study and future studies should blind investigators.

This study illustrates changes in biceps tendon structure are associated with changes in kinematics throughout a simulated game in youth softball pitchers. Optimal values of trunk flexion and rotation may be necessary to ease the stress placed on the biceps tendon. This is a basis for the development of pitch count limits for windmill softball pitchers.

## Conflict of Interest

The authors declare that they have no conflict of interest.

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