Acute Response of the Infraspinatus and Biceps Tendons to Pitching in Youth Baseball

ADAM J. POPCHAK1, NATHAN S. HOGABOOM2, DHARMESH VYAS3, JOHN P. ABT4, ANTHONY DELITTO5, JAMES J. IRRGANG1,3, and MICHAEL L. BONINGER2,6,7,8

1Department of Physical Therapy, University of Pittsburgh, Pittsburgh, PA; 2Department of Rehabilitation Science and Technology, University of Pittsburgh, Pittsburgh, PA; 3Department of Orthopaedic Surgery, University of Pittsburgh, Pittsburgh, PA; 4Sports Medicine Research Institute, College of Health Sciences, University of Kentucky, Lexington, KY; 5School of Health and Rehabilitation Sciences, University of Pittsburgh, Pittsburgh, PA; 6Human Engineering Research Laboratories, VA Pittsburgh Healthcare System, Pittsburgh, PA; 7Department of Physical Medicine and Rehabilitation, University of Pittsburgh, Pittsburgh, PA; and 8Department of Bioengineering, University of Pittsburgh, Pittsburgh, PA

ABSTRACT

POPCCHAK, A. J., N. S. HOGABOOM, D. VYAS, J. P. ABT, A. DELITTO, J. J. IRRGANG, and M. L. BONINGER. Acute Response of the Infraspinatus and Biceps Tendons to Pitching in Youth Baseball. Med. Sci. Sports Exerc., Vol. 49, No. 6, pp. 1168–1175, 2017. Purpose: Youth baseball frequently results in repetitive strain injuries. Quantitative ultrasound allows real-time imaging with the ability to identify acute markers of tendon change. The study objective was to determine acute quantitative ultrasound changes in the long head of the biceps and infraspinatus tendons of the throwing and nonthrowing shoulders during a pitching performance. We hypothesized the tendons of the pitching arm would exhibit an increased width and decreased echogenicity after pitching and that tendons of the nonpitching arm would not demonstrate such changes. Methods: Fifty youth baseball players, ages 9–14 yr, engaged in a simulated pitching performance that consisted of 50 pitches. Subjects underwent serial quantitative ultrasound imaging of the infraspinatus and the long head of the biceps before pitching and after 25 and 50 pitches were thrown. Results: Testing of the change in tendon width revealed the infraspinatus (0.21 mm) and long head of the biceps tendons (0.18 mm) in the throwing shoulder had statistically significant increases (P = 0.03) in tendon width as an acute response to throwing 50 pitches, without such changes in the nonthrowing shoulder (P > 0.05). No tendon width change was found at 25 pitches in either arm or tendon (P > 0.05). No associated changes in echogenicity were found at any time point (P > 0.05). Conclusion: The results of this study suggest that pitching acutely increases tendon width in two biomechanically important tendons of the shoulder as early as the 50 pitch mark. This change could be a normal physiological response or a potential warning sign of future pathology and requires further study. Key Words: SHOULDER, ULTRASOUND, THROWING, OVERUSE

Youth baseball can involve year-round participation (22,32) and high volume of play, and it inherently exposes the dominant arm to high levels of stress, frequently resulting in repetitive strain injuries and pain. There has been a significant rise in adolescent throwing injuries (22) and shoulder and elbow pain in youth, and the Little League Baseball is a well-recognized phenomenon (5,12,22,27,28,30,32). More than 50% of Little League pitchers experienced shoulder or elbow pain during the course of a season, with incidence often related to the duration of exposure (1). Recent reports found the incidence of shoulder pain was up to 35% (27,28) in pitchers every season, and individual pitching performances resulted in pain more than 9% of the time (27). Furthermore, a prospective study found 5% of pitchers who started at 9–14 yr old experienced a serious injury resulting in surgery or retirement from baseball during a 10-yr period (12).

Previous research has shown that pitching injuries are related to several factors, most of which are associated with overuse (12,27,28,37) and pitching despite fatigue (30). On the basis of previous research as well as expert consensus opinion, the belief is that many of the pitching injuries that require surgery or medical attention at older and higher levels of competition result from accrued microtrauma that was initiated in youth baseball (5,27). In response, guidelines have been established (26,37) to help reduce the risk of injury. However, because of the nature of accumulating microtrauma, it is difficult to carry out a study in which a definitive cause and effect relationship can be determined (27).

Ultrasound provides an imaging method that involves no radiation, is relatively inexpensive, and can identify acute markers of tendon change that may relate to risk of pathology in the future (10,38). The portability of ultrasound offers the ability to evaluate subjects at the field of play. Previous research has used specifically designed methods and markers to establish a reference to improve reliability (9) and through
gray scale–based quantitative ultrasound (QUS), objective, reliable measurements of tendon appearance can be obtained and may provide greater information about the etiology of injuries related to accrued microtrauma (9,10). Specifically, QUS features of tendon width and echogenicity have been shown to change with tendon degeneration (8), with tendinopathy presenting as an enlargement of the tendon with reduced echogenicity (2). Response to activity and loading leading to increases in tendon width may represent subclinical but cumulative damage to a tendon (31), whereas reduced echogenicity may represent more diffuse damage (11), collagen fiber disorganization, and edema. Understanding the behavior of these features may aid in identifying risk factors for and prevention of musculoskeletal injuries (8).

The purpose of this study was to investigate acute changes within two biomechanically important structures, the infraspinatus (INF) and the long head of the biceps (LHB) tendons, of the throwing shoulder during a pitching performance (before, after 25 pitches, and after 50 pitches) in youth baseball players through QUS imaging. The INF and the LHB were selected for analysis secondary to their high activity, propensity for overload, and role during the late cocking and deceleration phases of the throwing sequence (13). During pitching, the INF and the LHB are both placed under extreme eccentric demand and are vital in dissipating significant forces exposing them to overload. Bouts of exercise induce acute biochemical responses and can affect tendon structure (36), such as increasing tendon width and decreasing echogenicity on ultrasound measurements (38). Therefore, we hypothesized that the INF and the LHB tendons of the dominant throwing arm would exhibit an increased width and decreased echogenicity after completing a pitching performance and that the INF and LHB tendons of the nonpitching arm would not change.

MATERIALS AND METHODS

This was a prospective cohort study of healthy youth baseball players, between 9 and 14 yr of age, and was approved by the university’s institutional review board. Written informed consent of each participant and parent or guardian was obtained before the study. Subjects were eligible for participation in this study if they were currently playing baseball in an organized league and reported pitching as either their primary or secondary position. Subjects were excluded if they had a history of a shoulder or elbow injury that resulted in surgery, an injury to the throwing arm resulting in a loss of playing time within the last year, or if they had shoulder or elbow pain at the time of initial testing.

QUS Testing

Testing setup. Each subject was asked to refrain from throwing activities the day of the testing session to minimize the possibility of unwanted factors affecting the baseline recordings. They were encouraged to perform the typical warm-up activities (except throwing) they would follow before a game or practice. Warm-up activities were variable between subjects and not recorded but included light jogging and lower and upper extremity flexibility exercises. Baseline images were collected before the participant warming up for their pitching activity using actual throwing. Images were collected bilaterally to allow comparison between throwing and nonthrowing arms.

Testing procedure. QUS image of INF tendon and LHB. All subjects assumed a seated position in a standard chair. The arm being tested was kept adducted to the side of the thorax, with the elbow flexed to 90° and the forearm in full supination resting on a pad to maintain the position of the elbow. This position was used for testing of both the LHB (9) and the INF tendons (19). Ultrasound imaging was completed using a portable Biosound MyLab25 Gold ultrasound system (model 7340), with a 4.0- to 13.0-MHz linear array transducer (model LA523) (Bio Sound Esaote Inc., Indianapolis, IN) at various baseball training facilities and fields. Ultrasound settings were kept consistent throughout all testing, with shoulder tendon presets using a depth of 4 cm (9) and a gain of 70.

One operator (AP) performed the QUS imaging on all 50 participants. The examiner was trained in and followed a previously validated QUS protocol (8,9) for greater than 1 yr before the initiation of testing. Recommended scanning hours or number of cases required for competence vary, but findings indicate that less experienced clinicians have comparable accuracy with more experienced clinicians (23). The transducer location determination, the reference marker and transducer placement, the resultant interference pattern, and the definition of region of interest (ROI) were all similar in methodology to that described by Collinger et al. (9). Specifically for the LHB, the transducer was initially placed on the anterior aspect of the humeral head in the transverse direction to visualize the bicipital groove. The transducer was then rotated 90° to the longitudinal direction along the anterior humeral head and proximal humerus and oriented such that the LHB tendon was as parallel to the bone edge as possible with defined tendon borders. A steel marker was placed at the distal end of the transducer, which produced a hypoechoic interference pattern at the top of the image; this marker enhances reliability by providing a stable reference point that can be easily identified.

The INF was imaged by initially moving the transducer over the spine of the scapula from lateral to medial until the medial border of the scapula was reached. The transducer was then lowered inferiorly approximately half of the width of the probe into the INF fossa, where the transducer was guided in a lateral direction until the insertion of the INF tendon on the humeral head was visualized. Transducer orientation was then optimized to most accurately mimic the course of the INF from its origin to its insertion resulting in an image where the maximum amount of the INF tendon lay in the longitudinal fashion over the bone edge. The method for evaluating the INF has not been previously validated;
however, it followed similar methodology to that described by Collinger et al. (8,9).

Once an ideal location was identified, an external reference marker was taped to the skin at the distal (LHB) or the medial end (INF) of the transducer footprint. Serial images were then captured with an aspect of the transducer over the reference maker, resulting in an interference pattern on the image from which the ROI was determined. Images before (baseline), during (at 20–25 pitches), and after (50 pitches) throwing were collected and saved for later analysis.

An interactive Matlab (The Mathworks, Natick, MA) program was used to obtain information on tendon width and echogenicity as described previously (9). Briefly, the program uploads and presents the images to the user randomly and in a blinded fashion (9). The center of the interference pattern is identified by the user; the tendon ROI is then a standard distance from the center of the pattern. The user selects the tendon borders within the ROI, and a histogram is created containing grayscale values of all pixels within the tendon. Tendon width was determined by calculating the mean distance between the top and bottom borders, and echogenicity was calculated as the mean of all grayscale values within the histogram (Fig. 1).

**Pitching protocol.** All participants engaged in a standard pitching performance, with attempts made to replicate normal game play, including use of a pitching mound set to the distance that corresponded with the age and level of play of the participant, a catcher, and use of verbal encouragement to pitch with intensity and exertion as in game play. Attempts were made to standardize the length of pitching, with the first pitching exposure lasting approximately 20–25 pitches and the second exposure lasting 25–30 pitches. Secondary to what would be considered an extended inning (>25 pitches), the participant was encouraged to pace himself as he approached 20 pitches. At the end of both pitching exposures, QUS images were captured, and the pitcher was asked about discomfort in the shoulder or elbow region using a numeric rating scale (21) and their perceived level of exertion (33). The questions regarding pain and perceived exertion were asked to determine whether throwing needed to be halted or if encouragement was needed to pitch with more of a gamelike exertion. The testing session ended when the pitcher reached the final time point (50 pitches) or if they reported any pain with throwing or need to terminate testing. All coaches involved stated that they did not have their pitchers pitch to the upper limits of the age-adjusted guidelines (26) in the preseason or early in the season, when study testing took place, and in general were approximately 25 pitches below the recommended threshold.

**Statistical Methods**

Intraclass correlation coefficient (ICC) (model = one way, average measures) was determined for this study from the measurements associated with the prethrowing, 20–25, and 50 pitch count time points of the nonthrowing tendon for the LHB and the INF tendons. Standard error of the measurement (SEM) was then calculated using the following formula: SEM = SD from first measure \(\times \sqrt{1 - ICC}\).

Basic descriptive statistics (means, SD, frequencies) were calculated for all participant demographics and QUS

![Figure 1](http://www.acsm-msse.org)
The primary statistical analysis related to the status of the QUS measures, specifically tendon width and echogenicity. Repeated-measures ANOVA was performed to test the main effect of pitch count (0, 20–25, and 50) on each descriptor of the LHB and INF tendons. The analysis was run with no modifiers or covariates. Significance was set at $P < 0.05$. After a significant main effect, post hoc analyses using pairwise comparisons, with Bonferroni corrections, were performed to determine whether baseline and serial QUS measures were significantly different from one another, comparing all possible combinations for within-subject changes in the throwing and the nonthrowing shoulders. All statistical analyses were completed with IBM SPSS Statistics Software, version 22 (Armonk, NY: IBM Corp.)

**RESULTS**

**Intrarater reliability, SEM.** Results from QUS images taken by one rater for the LHB ($n = 43$) and the INF ($n = 44$) showed moderate to strong intrarater reliability for the QUS variables of tendon width (INF = 0.94, LHB = 0.91) and echogenicity (INF = 0.80, LHB = 0.91) for both tendons. The SEM values for the LHB tendon width and INF tendon width were 0.207 and 0.155 mm, respectively.

**Demographics.** Fifty healthy males ($n$ of each age: 9 yr = 4, 10 yr = 5, 11 yr = 18, 12 yr = 7, 13 yr = 12, and 14 yr = 4) participated in this study. Basic demographic information for the entire sample can be found in Table 1. Two participants were unable to continue pitching and further testing secondary to pain in the throwing arm (1) and time constraints (1).

Therefore, 48 subjects had complete pitching performances and data sets available for QUS analysis of the throwing arm. In some circumstances, the nonthrowing arm was unable to be examined with QUS secondary to practice and time limitations (INF $n = 4$), (LHB $n = 5$). Data related to pain or discomfort and perceived level of exertion reported during the pitching session can also be found in Table 1.

**Ultrasound results.** The mean, SD, and change values (difference when time point 1 or time point 2 were subtracted from baseline, time point 0) were determined for echogenicity and tendon width at each of the three time points (Table 2). The results of this study revealed the nonthrowing LHB was a significantly greater width at baseline compared with the throwing LHB ($P = 0.02$). No other differences existed in the baseline values of width or echogenicity between the throwing and the nonthrowing sides.

Echogenicity of the LHB ($P = 0.91$) and the INF ($P = 0.52$) tendons in the throwing arm were not significantly different across the three time points. Similar results were found in the nonthrowing arm for both tendons, LHB ($P = 0.26$) and INF ($P = 0.56$). Analysis of tendon width revealed statistically significant differences in both tendons of the throwing shoulder. Analysis of the dominant LHB ($P = 0.002$) was significant, with post hoc comparisons revealing a difference between the baseline (time point 0) width value and the value at the completion of 50 pitches (time point 2) of 0.18 mm (Table 2). A larger post hoc difference was found between time point 1 and time point 2 for the LHB (Mean difference = 0.21) (Table 2). Analysis of the INF was shown to violate the assumption of sphericity, indicating significant differences among the variances of the values between each pitch count level that could influence the $F$ values. Therefore, the more conservative correction of the $F$ value, the Greenhouse–Geisser correction was used. This correction resulted in a significant within-subjects effect for tendon width of the INF ($P = 0.01$) of the dominant shoulder. Post hoc comparisons revealed a significant difference between the baseline (time point 0) width value and the value at the completion of 50 pitches (time point 2), with a mean difference of 0.21 mm (Table 2).

No differences were found in tendon width between baseline (time point 0) and 25 pitches (time point 1) for either tendon ($P > 0.05$). A graphical comparison of the throwing and nonthrowing arms shows the behavior of each tendon throughout the three time points (Figs. 2 and 3).

**TABLE 1. Demographic information.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
<th>Frequency</th>
<th>Pct.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>11.60 ± 1.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>156.67 ± 13.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>49.38 ± 14.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI</td>
<td>19.71 ± 3.44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. leagues</td>
<td>2.0* ± 0.82 range (1.0–4.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Years pitched</td>
<td>3.0* ± 1.78 range (1.0–8.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Throwing arm, right</td>
<td>39/50 78.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1* position pitcher</td>
<td>22/50 44.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2* position pitcher</td>
<td>28/50 56.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Pitching Session Information**

<table>
<thead>
<tr>
<th>Pain/discomfort</th>
<th>0.0* range (0–3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perceived exertion</td>
<td>7.0* range (0–10)</td>
</tr>
</tbody>
</table>

*Median value.

**TABLE 2. Mean echogenicity and tendon width for repeated measures.**

<table>
<thead>
<tr>
<th>QUS Variable</th>
<th>Tendon</th>
<th>Arm Side</th>
<th>Baseline (Mean ± SD)</th>
<th>Time 1 (25 Pitches) (Mean ± SD)</th>
<th>Time 2 (50 pitches) (Mean ± SD)</th>
<th>Change 1—BA</th>
<th>Change 2—BA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echogenicity</td>
<td>LHB</td>
<td>Throwing</td>
<td>125.84 ± 19.83</td>
<td>125.20 ± 16.56</td>
<td>124.82 ± 19.60</td>
<td>-0.64</td>
<td>-1.02</td>
</tr>
<tr>
<td></td>
<td>LHB</td>
<td>Nonthowing</td>
<td>126.18 ± 21.55</td>
<td>129.74 ± 16.30</td>
<td>127.90 ± 16.23</td>
<td>3.56</td>
<td>1.72</td>
</tr>
<tr>
<td></td>
<td>INF</td>
<td>Throwing</td>
<td>129.75 ± 23.21</td>
<td>130.83 ± 2.56</td>
<td>129.76 ± 21.96</td>
<td>2.88</td>
<td>1.81</td>
</tr>
<tr>
<td></td>
<td>INF</td>
<td>Nonthowing</td>
<td>128.94 ± 22.90</td>
<td>131.12 ± 17.98</td>
<td>127.86 ± 18.28</td>
<td>2.18</td>
<td>-1.08</td>
</tr>
<tr>
<td>Width</td>
<td>LHB</td>
<td>Throwing</td>
<td>4.06 ± 0.78</td>
<td>4.03 ± 0.76</td>
<td>4.24 ± 0.74</td>
<td>-0.03</td>
<td>0.18 i</td>
</tr>
<tr>
<td></td>
<td>LHB</td>
<td>Nonthowing</td>
<td>4.42 ± 0.68</td>
<td>4.29 ± 0.88</td>
<td>4.43 ± 0.82</td>
<td>-0.13</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>INF</td>
<td>Throwing</td>
<td>4.34 ± 0.64</td>
<td>4.51 ± 0.63</td>
<td>4.69 ± 0.65 i</td>
<td>0.12</td>
<td>0.21 i</td>
</tr>
<tr>
<td></td>
<td>INF</td>
<td>Nonthowing</td>
<td>4.45 ± 0.62</td>
<td>4.43 ± 0.59</td>
<td>4.40 ± 0.63</td>
<td>-0.02</td>
<td>-0.05</td>
</tr>
</tbody>
</table>

BA: baseline; CI: confidence interval.

iBaseline to 50 pitches, post hoc analyses: 95% CI (0.02–0.35), $P = 0.03$, effect size $d = 0.25$.

j25 pitches to 50 pitches, post hoc analyses: 95% CI (0.08–0.35), $P = 0.001$, effect size $d = 0.28$.

kBaseline to 50 pitches, post hoc analyses: 95% CI (0.02–0.41), $P = 0.03$, effect size $d = 0.31$. 
The amount of change in the dominant shoulder LHB and INF tendons for each subject is shown in Figure 4. Mean change experienced in the LHB was determined to be 0.18 mm and ranged from 1.06 to 1.50 mm. Mean change in the dominant INF tendon was 0.21 mm, with a range of 1.48 to 1.24 mm.

**DISCUSSION**

The main objective of this study was to determine whether changes occurred in tendons of the shoulder in a healthy adolescent population during a pitching exposure. Acute changes in tendons of the shoulder have been shown to occur in response to other upper extremity activities (10); however, such changes have yet to be documented in youth pitchers. The results of this study indicate acute changes occur in the LHB and INF tendons of the throwing shoulder in response to pitching. LHB and INF tendon width increased at 50 pitches, with the amount of change seen exceeding the error of measurement. No differences were noted in tendon width in the nonthrowing arm when compared at any time points.

Exercise or high-intensity loading and activity can stimulate adaptations in tendons that can be positive, but also may play a role in development of tendon injuries (20,36). Acute responses to exercise in the loaded tendon include collagen turnover, increased blood flow, and influx of inflammatory products (36). These responses are reported to be influenced by both activity duration and intensity and may lead to a pathological state (36). Previous studies have shown a nonsignificant trend toward increased tendon thickness with acute activity (14,38). Acute increases in LHB tendon width of approximately the same magnitude (0.22 mm) and effect size ($d = 0.24$) as seen in this study were found after a high-intensity wheelchair sport activity (38) and were positively correlated with the duration of play, suggesting the duration of exposure may be an important determinant (38). A noted difference between the previous studies (14,38) and this study, in addition to the study population, was that not all subjects were tested immediately postactivity, with some testing not occurring for 20 to 30 min after the event (14,38). The changes in tendon thickness in this study were based off of measurements taken immediately (within 5 min) after the completion of the throwing activity. However, on the basis of the mean difference and effect size noted in a previous study (38) and this study, it appears that timing of the testing did not drastically effect the results. Our investigation did not account for factors outside of pitching that may have contributed to change seen in the tendons. High metabolic activity is present in human tendons and allows the tendon to adapt to changing demands (29). Factors such as the history and rate of mechanical loading, temperature fluctuations, and fluid shifts have been proposed to stimulate changes in tendon properties (24,29). We believe that if the differences seen in tendon width of the dominant arm were the result of systemic factors, changes would have been seen in both shoulders. The absence of bilateral findings increases the likelihood that mechanical loading was the cause of change.

Our study did find that some of the participant's tendons in the throwing arm experienced a decrease in tendon thickness (Fig. 4). The acute effect of exercise in terms of tendon width has shown to be variable. Previous studies have reported an immediate postexercise decline in tendon thickness (16,39) ranging from 5% to 20%. In vitro models have suggested cyclic loading may exude water from the tendon, reducing tendon dimensions (17,18,25). The extrusion of water may be related to crimp straightening and collagen realignment and

![FIGURE 2—LHB width at three pitch counts by arm side.](http://www.acsm-msse.org)
stretching that leads to a positive hydrostatic pressure and thus fluid movement out of the tendon (7,17,18,25). Variability in tendon width response has also been reported by Lamir, Salant, and Foux (25) where diameter decreased under constant axial strain, implying loss of fluid from the tendon. However, under higher strain level, with sufficiently long rest periods between loads as opposed to constant strain, the diameter was found to increase above its original level, implying damage to the restraining elements that maintain structural integrity (25). Shalabi et al. (34) found a 12% increase in tendon volume as an immediate response to high load eccentric strength training, described as increased water content or hyperemia. They suggested (34) pathological changes in tendons may be related to proteoglycan macromolecules and their protein core, which provide mechanical support and are strongly hydrophilic. Increased amounts of a specific protein core (GAG) may trap water in increased amounts and are characteristic in chronic tendinosis (34). It is possible that the variation in tendon response seen in our study was related to the protein core distribution in each tendon, with some tendons being closer to a pathological state, retaining more water. Whereas other tendons were healthier, with lower concentrations of GAG resulting in less water retention. The water binding potential of the proteoglycans may be a major factor in bringing about the immediate changes in tendon width (34). The relationship between the amount of GAG and tendinopathy creates the possibility that tendinopathy may mediate the acute response to exercise, causing opposite reactions in healthy versus less healthy tendons (34). In either case, this study was able to identify that change occurred as a result of mechanical loading, which theoretically could lead to overload if not addressed.

Our study found no difference in echogenicity in either the throwing or nonthrowing arm. The use of echogenicity as a measure of tendon property has recently been called into question (35) secondary to additional factors present during in vivo testing, where muscle contraction increased the variability of echogenicity measurements. However, our current study examined tendons at rest, with no movement or active muscle contraction. The correlation of echogenicity and clinical measures of shoulder pain and pathology has been validated in a previous study (8). In addition, echo intensity was found to decrease after mechanically induced damage to tendons, indicating reduced echogenicity may represent a diffuse damage in the tendon (11). On the basis of this established relationship (8,11) between echogenicity and tendinopathy, and the fact that our study examined only healthy pitchers with no recent history of pathology, it is reasonable to that we found no change in echogenicity.

The acute width changes seen in the LHB and INF tendons of the throwing arm may be part of a continuum that leads to pain and more chronic pathology over time (38); however, this study does not provide proof of this relationship. Traditionally, there has been consensus that tendons endure subclinical but cumulative damage over time before identified pathology (31). The tendinosis continuum is generally
believed to begin with mechanical overloading that surpasses the repair mechanisms (31,40). Applying this principle to the tendons of youth and adolescent pitchers would suggest that it is vital to monitor for acute overload that would proceed further down the continuum and that adequate rest and recovery should be used to allow the tendon to return to its original state.

The results occurred by the 50 pitch mark. In addition, the increase in tendon width seen from baseline to 50 pitches for both the LHB and the INF tendons would suggest that continued pitching beyond this point might result in continued acute changes in tendon width (Figs. 2 and 3). The link between increased pitching and shoulder pain and pathology has been documented (12,27,28,37); however, cumulative trauma has been difficult to describe (27). To our knowledge, this is the first study to show clinical data that suggests throwing at least 50 pitches results in acute changes in the tendon.

Multiple organizations have established and implemented guidelines and pitching rules in attempts to prevent youth pitching injuries (3,4,26). Two studies by Lyman et al. (27,28) concluded that throwing more than 75 pitches per game and having higher pitch counts, in a game and during a season, significantly increased the risk of experiencing shoulder pain. In addition, a study by Olsen et al. (30) found a fourfold increase in risk for having a surgical history when throwing more than 80 pitches per game. The results of these studies represent persuasive evidence to limit pitches to 75 per game to lower the risk of upper extremity complaints in youth and adolescent pitchers. The results of our current study correspond with the findings previously mentioned (27,28,30). In fact, the acute change in tendon thickness was seen approximately 25 pitches sooner than the current guidelines recommended as a single exposure limit. The pitchers tested in the current study experienced a range of tendon width changes when measured at 50 pitches. It is possible the individual variation in response to pitching could be a predictor of injury, although such a conclusion is not possible from this study. Further work investigating individual acute responses and their relation to pain is needed to make this determination. In addition, it is possible that the techniques used in this study could be used to test interventions such as exercise or changes in throwing mechanics to see if they effect tendon response.

The limitations of this study should be noted. The results of this study are based on a homogenous group of youth and adolescent pitchers with no previous history of throwing injury for the past year and no current complaints with throwing. Inclusion of other populations may determine whether individuals with a relatively recent history of pathology react differently to pitching. Second, maximizing pitching effort and intensity to match that of game intensity was difficult. Attempts were made to encourage full effort, regardless of the practice environment and situation, and tracking of perceived exertion at each time point allowed investigators a mechanism to quantify intensity. However, one cannot assume all pitchers would behave the same in an actual game environment. Third, testing took place at team facilities during practice activities. The actual live practice setting was preferable for recreating a gamelike environment yet did not allow high levels of control over extrinsic factors. Fourth, we performed QUS imaging on an aspect of the LHB—approximately the inferior one-third of the bicipital groove—that optimizes collagen fiber reflection. It is possible that our analysis would have provided more information if we imaged the proximal origin, which experiences high forces during the late cocking and follow-through phases of the throwing motion at the biceps anchor (6). However, we believe, obtaining reliable images of the widest part of healthy tendons provides a worthy compromise. In addition, baseline width values of the LHB were found to be significantly larger in the nondominant arm. As the baseline measures were cross-sectional in nature, tendon plasticity, intermuscular differences (15), and one extreme value in both sides may have accounted for the statistical difference. Nevertheless, we do not believe this finding affects the results of the repeated-measures testing that occurred during a single pitching exposure, as adequate intrarater reliability was achieved. Also in regard to QUS, the imaging technique of the INF used in this study has not been validated. However, the methods described followed a similar protocol to that of the LHB, which has been previously validated (9). In addition, the intrarater reliability and the SEM achieved for the INF and the LHB in this study were similar. Finally, and most notably, the coaches and parents who participated in the study were not willing to pitch beyond 50 pitches during preseason practices. We believe that continued pitching beyond this point would have resulted in greater acute changes in both tendons. We recommend future testing on acute tendon changes with pitch count progressing to at least 75 pitches to further demonstrate the changes that occur during extended pitching performances. Future testing should also investigate factors that influence the size of tendon response and its relationship with future injury.

CONCLUSION

A brief pitching exposure induced an acute increase in tendon width in both the LHB and the INF tendons of the throwing shoulder, with no associated decrease in echogenicity. A detected increase in tendon width as early as 50 pitches could indicate a reaction of the tendon in response to the overload experienced during pitching, which is visible 25 pitches sooner than the current upper limits of the pitch count recommendations for this age-group. Additional work is needed to identify the effects at higher pitch counts and its correlation to the development of pain or pathology as well as the factors related to individual variations in tendon response.

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