Fatigue of the Dynamic Stabilizers of the Medial Elbow in Baseball Pitchers

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Background: The flexor carpi ulnaris and flexor digitorum superficialis are thought to provide dynamic stability to the medial elbow during pitching. High medial elbow stress during pitching fatigues these dynamic stabilizers of the medial elbow. This fatigue of dynamic stabilizers could leave the ulnar collateral ligament more vulnerable to the stress of pitching.

Purpose/Hypothesis: The purpose of this study was to identify the onset of fatigue in the dynamic elbow stabilizers during a pitching performance. It was hypothesized that middle finger (MF) and ring finger (RF) fatigue during a pitching performance would occur earlier and be more substantial than grip and 3 finger grip fatigue.

Study Design: Descriptive laboratory study.

Methods: Eighteen baseball pitchers (age, 17 ± 4 years) threw 4 innings of a simulated game (16 pitches per inning plus 5 warm-up pitches per inning). Before the game and after each inning, MF flexion, RF flexion, and grip strength were recorded. A standard full grip (FG) and a modified 3-finger grip (3FG) test were employed. Fatigue was classified as marked (>20% loss), moderate (10%-20% loss) or minimal (<10% loss).

Results: MF strength was greater on the dominant versus nondominant hand (7%; $P = .04$). There was no hand dominance effect for the other 3 tests (RF, $P = .15$; FG, $P = .79$; 3FG, $P = .90$). The fatigue responses differed significantly between tests ($P < .001$). After the fourth inning, MF fatigue (21%) was greater than RF (7%; $P < .001$), FG (5%; $P < .002$), and 3FG (5%; $P < .001$) fatigue. MF fatigue was evident early and was progressive. After the first inning, 4 pitchers (22%) had marked MF fatigue and 3 (17%) had moderate MF fatigue. By the end of the fourth inning, 10 pitchers (56%) had marked MF fatigue and 6 (33%) had moderate MF fatigue. By contrast, only 5 pitchers (28%) had marked RF fatigue after 4 innings, and only 3 pitchers (17%) had marked FG or 3FG fatigue. Pitchers with high valgus elbow torque during pitching had greater MF fatigue than pitchers with lower elbow valgus forces (22% vs 10%; $P = .045$).

Conclusion: By the end of the fourth inning, 10 pitchers (56%) had marked MF fatigue and 6 (33%) had moderate MF fatigue. MF fatigue may be indicative of medial elbow dynamic stabilizer fatigue in pitchers.

Clinical Relevance: We recommend finger flexor strength training to help support the medial stabilizers of the elbow during pitching. In the future, MF fatigue testing could be an ''in-game'' measure of pitcher fatigue.

Keywords: baseball/softball; pitcher; UCL; elbow; medical aspects of sports; muscle injuries; injury prevention

The muscles of the flexor pronator mass can provide dynamic stability to the medial elbow.[3,5,6,8,11,13,14,17] Specifically, the flexor carpi ulnaris (FCU) and the flexor digitorum superficialis (FDS) have been shown to provide dynamic stability, with a lesser contribution from the pronator teres (PT).[6,13,14,17] Active contraction of the wrist and finger flexors has been shown to decrease valgus load under a static maximal grip contraction,[14] highlighting the importance of these secondary stabilizers for ulnar collateral ligament (UCL) stability. In line with these findings,[3,5,6,13,17] exercise-induced wrist flexion fatigue has been shown to increase medial elbow gapping under valgus stress.[11] The FDS and FCU are highly active during the acceleration and deceleration phases of the pitching motion[4] (FDS, 80%-71% of maximal voluntary contraction [MVC]; FCU, 112%-77% of MVC) and likely provide dynamic elbow stability. In support of this, FCU elasticity has been shown to increase after repeated pitches and this

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change has been correlated with an increase in medial elbow joint space.[11,15]

Previous work on muscle fatigue after pitching performances[7,9,10,11] indicated that grip strength may be an insensitive test of the demand placed on the forearm muscles during pitching. Grip strength during pitching performances ($\leq$100 pitches) has not been shown to fatigue by >5%.[7,9,10,11] Based on the elevated electromyography (EMG) activity recorded in the FCU and FDS during pitching, it seems highly probable that these muscles would fatigue substantially. Therefore, grip testing may not be selective for the FCU and FDS. Recently, middle finger (MF), and to a lesser extent ring finger (RF), flexion strength testing appear to be a better indicator of fatigue and muscle damage in the dynamic stabilizers of the medial elbow.[7] EMG work of McHugh and Mullaney[7] suggests that the MF and RF strength tests are highly selective for the FCU (66%-93% of MVC) and FDS (61%-74% of MVC) while being less selective for the PT (23%-35% of MVC). In the field, postgame (58 $\pm$ 18 pitches) fatigue was as high as 12% for MF testing and 6% for RF testing, while standard grip strength measurements showed no postpitching strength loss.[7]

In response to the increased prevalence of elbow injuries in baseball, there has been increased interest in measuring the stress in the medial elbow during pitching. To this end, a wearable inertial sensor has been developed to quantify medial elbow torque during pitching.[2,7,12] Medial elbow valgus torque, an index of valgus stress on the elbow, was shown to be greater for fastballs and changeups compared with curveballs.[12] Additionally, valgus torque increased in later innings of a simulated game, despite a decline in pitch velocity, and this effect was attributed to fatigue.[12] McHugh and Mullaney[7] investigated the association between elbow valgus torque during pitching and muscle fatigue in the dynamic stabilizers of the elbow of collegiate pitchers. Pitchers with high valgus torque (>50 N·m) had greater postgame MF and RF flexion fatigue than those pitchers with a low valgus torque ($\leq$50 N·m). It is possible that pitchers with high valgus torque during pitching experience earlier fatigue of the dynamic stabilizers of the elbow and thus are at increased risk of injury. The time course of fatigue during a pitching performance has not been examined.

Therefore, the purpose of this study was to determine the most sensitive test of forearm fatigue in baseball pitchers. It was hypothesized that MF and RF flexion fatigue would be more sensitive indices of fatigue than grip strength or modified 3-finger grip (3FG) strength over 4 innings of pitching. Additionally, it was hypothesized that pitchers with greater valgus elbow torque would experience greater fatigue in the finger flexors.

METHODS

This study was approved by the Northwell Feinstein Institute for Medical Research, Northwell Health Institutional Review Board (IRB #21-0698). All participants were verbally educated on the study, and each provided informed consent before any data collection. This study was a simulated 4-inning game with high school and collegiate baseball pitchers examining elbow valgus torque and muscular fatigue in MF and RF flexion and grip tests.

Procedures

The study participants were 18 baseball pitchers (age, 17 $\pm$ 4 years; height, 1.78 $\pm$ 0.73 m; body mass, 76.5 $\pm$ 13.1 kg). All pitchers were high school or collegiate-level pitchers, and testing was performed based on participant availability. All testing was performed during the off-season to prevent any influence of in-season fatigue or pitch volume risk. All pitchers filled out a Kerlan-Jobe Orthopaedic Clinic Shoulder & Elbow test before participating. Pitchers needed to score $\geq$90 to participate in the data collection. Pitchers were instructed that they would pitch 4 innings with 21 total throws per inning. Data were collected on an indoor standard-sized mound. Elbow valgus torque was measured from an inertial measurement unit (Motus Global), housed in a compression sleeve, worn on the elbow during the entire 4-inning pitching session. The elbow valgus torque from the session was averaged for each inning and for each pitcher. Pitch velocities were collected (Pocket Radar) for each pitch and averaged for each inning. Each pitcher warmed up at his own self-selected pace as he would before a pitching performance. These pre–warm up throws were not counted. At the start of the study, pitchers were instructed to throw 5 warm-up pitches of choice per inning followed by 16 game pitches (10 fastballs, 4 curveballs, 2 change-ups) that were called by the catcher (K.B.). Pitchers were given the choice of pitching from the stretch or full wind-up. Fastballs were not categorized as 2-seam or 4-seam. Testing was done with 2 pitchers at a time, alternating innings as they would in a game situation. Each pitcher worked at a different speed, pitching, while the other pitcher was undergoing various strength tests and downloading torque data. The time between

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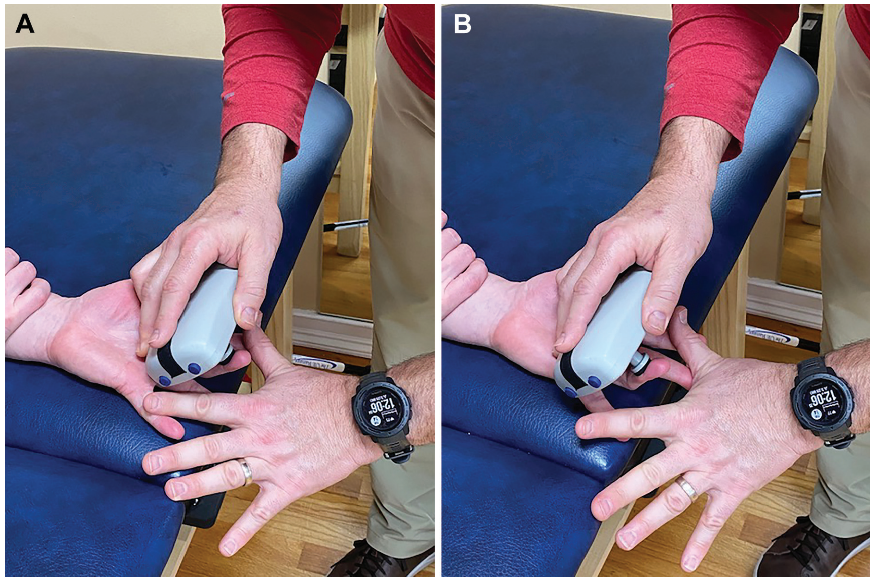

Figure 1. (A) Midde finger break test: The dynamometer probe was placed distally on the middle phalanx. The patient flexed maximally against the dynamometer while the tester extended the finger (break test). (B) Ring finger break test: The dynamometer probe was placed distally on the fourth phalanx. The patient flexed maximally against the dynamometer while the tester extended the finger (break test).

innings was between 12 and 15 minutes based on these factors.

Before the pitching session and after each inning, MF and RF flexion strength were tested as described previously.[7] Finger flexion strength was performed with a hand-held dynamometer (Lafayette Instruments). Participants were seated for testing with the elbow flexed approximately 40°, with the forearm supinated and rested on a flat surface with the wrist in neutral position. The participant stabilized his forearm with the contralateral hand, pressing it firmly against the table. The participant then flexed the test finger (MF or RF) while the tester (M.Mu.) stabilized the other 3 fingers against the table. This stabilization technique of the distal forearm and nontest fingers limited the pitcher's ability to perform wrist flexion or extension during the finger strength testing. Then the tester placed the 1 cm–diameter probe of the dynamometer distally on the middle or fourth phalanx (Figure 1, A and B). The patient maximally flexed the test finger against the dynamometer while the tester extended the finger (break test). Two trials were performed for each test. A third trial was performed if there was a marked difference between the first 2 trials (>30%), and subsequently the outlier was discarded. Index finger flexion break test strength has previously been shown to be a reliable measurement.[1]

Grip strength measurements were taken in a standing position using a hydraulic hand dynamometer (Jamar; Performance Health). Pitchers were instructed to have their shoulders adducted and neutrally rotated, elbow flexed at 90°, and forearm in the neutral position during a full grip (FG) and a modified 3FG test. Modified 3FG test utilized index, MF, and RF with the base of the grip dynamometer firmly planted into the thenar eminence (Figure 2). This was designed to limit the influence of thumb and fifth-digit strength and isolate those muscles that influence FDS and FCU EMG activity. Pitchers were instructed to squeeze the dynamometer as hard as they could for 3 to 5 seconds (isometric test). A mean of 2 trials was recorded.

Before commencing pitching, the inertial measurement unit was aligned with the medial aspect of the ulna approximately 5 cm distal to the medial epicondyle of the humerus and held in place with the Motus Pulse (Driveline Baseball) arm strap. In addition to elbow torque (peak elbow valgus torque), the sensor calculated arm slot angle (angle of forearm relative to the ground at ball release), arm speed (peak forearm angular velocity in degrees per second), and shoulder rotation angle (angle between forearm and ground at maximal external rotation).

Simulated Game Study Statistics

The fatigue response for the 4 strength tests was compared with 4 x 4 (innings by test) repeated-measures analysis of variance. Fatigue was classified as marked (>20% loss), moderate (10%-20% loss) or minimal (<10% loss). Based on previous work with these tests,[7] it was estimated that there would be 80% power to detect a 10% difference in fatigue between tests with 18 pitchers ($P < .05$). Alpha level set at <0.05. SPSS version 29 (IBM) was used for statistical analysis.

RESULTS

The pitchers threw 64 simulated game pitches and 5 mound warm-up pitches before each inning (84 throws).

Figure 2. Three-finger grip test: The patient held the first and fifth digits off of the grip dynamometer and attempted to squeeze with his middle 3 fingers.

TABLE 1
Fatigue for MF, RF, FG, and 3FG Tests[a]

	MF	RF	FG	3FG
First inning	91 ± 12[b]	107 ± 28[c]	100 ± 10[c]	102 ± 14[c]
Second inning	86 ± 12[b]	99 ± 18[c]	99 ± 13[c]	100 ± 14[c]
Third inning	81 ± 14[b]	95 ± 19[c]	95 ± 12[c]	97 ± 17[c]
Fourth inning	79 ± 11[b]	93 ± 15[c]	95 ± 15[c]	95 ± 14[c]
Effect of inning	$P < .001$	$P = .04$	$P = .04$	$P = .33$

[a]Data are presented as strength, as percentage of baseline. Effect of innings, $P < .001$; effect of test, $P < .001$; innings by test, $P = .59$. MF fatigue was greater than RF ($P < .001$), FG ($P < .002$), and 3FG ($P < .001$) fatigue. MF, middle finger; RF, ring finger; FG, full grip; 3FG, 3-finger grip.
[b]Significantly below baseline strength ($P < .05$).
[c]Significantly greater fatigue in MF ($P < .05$).

MF strength was greater on the dominant versus nondominant hand at baseline (7%; $P = .04$). There was no dominance effect for the other 3 tests at baseline (RF, $P = .15$; FG, $P = .79$; 3FG, $P = .90$). The fatigue responses differed significantly between tests ($P < .001$). After the fourth inning, MF fatigue (21%) was greater than RF (7%; $P < .001$), FG (5%; $P < .002$), and 3FG (5%; $P < .001$) fatigue. MF fatigue was evident early and progressive through the 4 innings (Table 1). After the first inning, 4 pitchers (22%) had marked MF fatigue and 3 (17%) had moderate MF fatigue. By the end of the fourth inning, 10 pitchers (56%) had marked MF fatigue and 6 (33%) had moderate MF fatigue. By contrast, only 5 pitchers (28%) had marked RF fatigue, and only 3 pitchers (17%) had marked FG or 3FG fatigue after the fourth inning.

Effect of Valgus Torque on Strength

The overall elbow valgus torque did not change from inning to inning ($P = .48$). The 5 pitchers who had greater torque (>50 N·m) had a mean MF flexion strength loss of 21.6% from the first inning to completion of the fourth inning. The 13 pitchers who had a low torque (≤50 N·m) had a mean MF flexion strength loss of 10.1% from the first inning to completion of the fourth inning ($P = .045$) (Figure 3).

Effect of Pitch Velocity on Fatigue

The mean velocity of pitches was 64 ± 5 mph. Pitch velocity did not differ from the first inning to the fourth inning ($P = .60$). MF fatigue did not differ between the high-velocity group (>65 mph; n = 10) and the low-velocity group (<65 mph; n = 8) ($P = .38$). Pitch velocity did not differ between the pitchers with high versus low elbow torque ($P = .71$).

DISCUSSION

It was hypothesized that there would be greater fatigue in the MF and RF tests versus the 2 grip tests. This hypothesis was partially confirmed. There was marked MF fatigue that was substantially greater than each of the other 3 tests. The RF and FG tests only showed mild fatigue after 4 innings, while 3FG did not show any significant fatigue.

This study also confirmed the previous findings[7] of greater MF fatigue in pitchers with a valgus torque >50 N·m. Although no studies have shown that this increase in torque and fatigue correlates with an increased rate of UCL injuries, there is a strong suspicion that both individually and together could lead to UCL injuries. This indicates that pitchers with high valgus elbow stress place greater demand on the dynamic stabilizers and thus exhibit greater MF flexor strength loss. However, velocity and torque were not correlated. This was surprising, considering that previous work suggests higher velocities are correlated with greater valgus forces.[16] However, this velocity-to-torque relationship is more pronounced within pitchers throwing different velocities than between pitchers.[16] This indicates the potential importance of identifying high valgus elbow torque pitchers. Identifying high valgus torque pitchers provides the opportunity to assess for earlier fatigue and potential injury. This progressive fatigue may lead to progressive stress on the UCL each inning as the pitcher fatigues.

In the previous related study, McHugh and Mullaney[7] tested 10 collegiate pitchers (21 years old) with a mean pitch velocity that was greater, 80 mph to 87 mph,

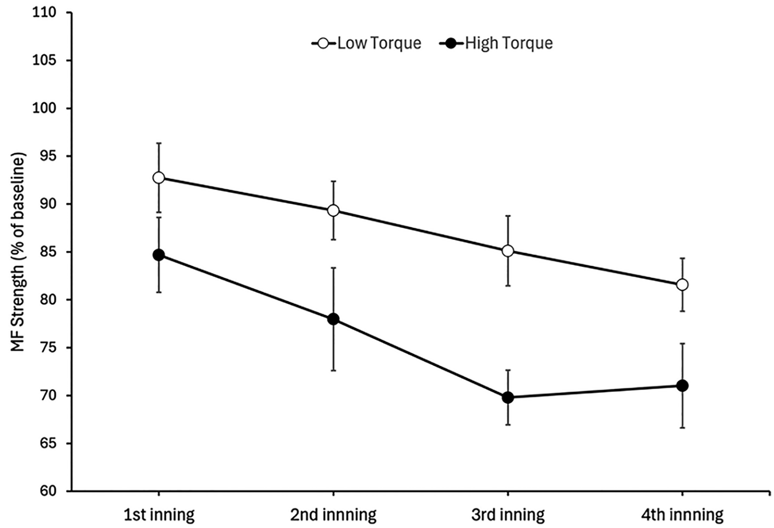

Figure 3. High valgus torque (n = 5) (filled circles) showed a mean of 21.6% loss in middle finger (MF) strength vs low valgus torque (n = 13) (open circles), which showed a mean of 10.1% loss of strength across 4 innings (*P* = .045).

a mean elbow torque of 51 N·m, and MF fatigue 88% of baseline for the high torque pitchers and 107% of baseline for the low torque pitchers after a mean of 58 pitches. The present study included a younger sample of pitchers, throwing with less velocity and less elbow torque, yet MF fatigue was noticeably greater. Thus young pitchers may be more susceptible to fatigue of the dynamic stabilizers of the elbow. The fact that such substantial MF fatigue was evident after only 4 innings (64 pitches) points to the importance of assessing fatigue in pitchers throwing a much larger number of pitches.

While the results of this study point to the potential utility of finger flexion strength measures in baseball pitchers, it is important to establish the reliability of this measure and the degree of testing expertise required to obtain reliable measures. The tester (M.M.) has >20 years of experience using this hand-held dynamometer to test baseball pitchers in both clinical and research settings. Had there been substantial measurement variability, it would not have been possible to detect these differences between tests and differences between elbow torque groups. However, since this is not a widely used strength test, it remains to be seen how useful the measurement is in the hands of other clinicians or if other finger flexion measurement devices on the market could offer similar potential. The utilization of this testing method, or something else on the market that better isolates the finger strength, could be used not only for similar research studies but may also lead to the potential application of in-game fatigue monitoring for pitchers. Such monitoring could lead to in-game decision-making or progression back to pitching.

Limitations

This study does present some limitations that need to be considered while interpreting the findings. This was a convenience sample using collegiate and high school pitchers of varying ages. This would leave the findings up to interpretation as to whether they would be applicable to younger or more experienced pitchers. The testing protocol was performed on only 1 occasion for each pitcher. Repeating the protocol may offer more insight into individual pitcher fatigue rates. We did not screen pitchers for any finger-strengthening programs that may currently be utilized. This could lead to the fatigue effects of pitchers utilizing a conditioning or fatigue program versus those pitchers not currently on a program. Finally, no commercially available finger flexion testing devices were on the market during this study. This testing technique was designed to stabilize both the forearm and the nontest fingers to prevent any wrist flexion or extension, similar to a commercially available finger flexor device currently available on the market.

CONCLUSION

All pitchers showed progressive MF strength loss from the first to the fourth inning; however, pitchers with greater valgus elbow torque during pitching experienced greater fatigue in the MF strength test. These pitchers may benefit from finger flexion strength training to maintain dynamic stability of the medial elbow during a pitching performance.

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