Assessment of Elbow Torque and Other Parameters During the Pitching Motion: Comparison of Fastball, Curveball, and Change-up

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Purpose: To assess the precision of a new wearable device in detecting medial elbow torque during the pitching motion in competitive baseball pitchers and to determine the differences in torque across pitch types and thrower demographic characteristics. **Methods:** High school and collegiate baseball pitchers were recruited from August 1, 2016, to January 31, 2017, through direct request by athletic trainers and coaches. Body dimensions and throwing arm measurements of the participants were collected. The sensor was positioned directly over the medial elbow and pitchers were instructed to throw 8 fastballs, 8 curveballs, and 8 change-ups in a standard, randomized sequence. The sensor reported elbow torque, arm speed, arm slot, and shoulder rotation, whereas a radar gun measured peak ball velocity. Precision was calculated by measuring outlier rate, and mixed model regression analysis was performed to detect differences in throwing biomechanics among pitch types. **Results:** In total, 37 competitive baseball pitchers were included in the study. The device had a precision of 96.9% for fastballs, 96.9% for curveballs, and 97.9% for change-ups. The device was sensitive enough to distinguish pitches according to elbow torque, arm speed, arm slot, and shoulder rotation. Fastballs caused the greatest relative torque across the medial elbow (average = 45.56 N m), compared with change-ups (43.77 N m; $P = .006$) and curveballs (43.83 N m; $P = .01$). Ball velocity contributed most to medial elbow torque ($P = .003$), followed by elbow circumference ($P = .021$), where smaller elbow circumference predicted greater medial elbow torque. **Conclusions:** The sensor is a precise and reproducible device for measuring torque across the medial elbow, as well as additional parameters of arm speed, arm slot, and shoulder rotation. Torque was significantly relatively higher in fastballs than curveballs and change-ups. **Level of Evidence:** Level III, comparative study.

The recent rise in shoulder and elbow injuries due to overuse in youth pitchers is well documented.[1,2] In particular, there has been increased awareness of the rise in elbow injury in youth and adult baseball pitchers, especially with regard to ulnar collateral ligament (UCL) injury.[3] In fact, recent studies have shown that only a small minority of youth baseball players have prescribed to being "pain free" in their throwing arm,[4] providing further evidence of the prevalence of overuse injury in this patient population. Despite significant efforts to establish safe pitching guidelines, these injuries continue to mount.

Multiple risk factors have been identified that contribute to overuse injury of the shoulder and elbow. These include pitching year-round,[5,6] pitching in multiple leagues,[7,8] pitching without adequate rest between sessions,[6,8] as well as pitching with high velocity,[5,6] pitching high numbers of breaking or off-speed pitches,[8,9] and pitching with improper or underdeveloped mechanics.[10-12] Several recent studies[9-17] have attempted to quantitatively assess pitching kinematics and their role in injury prevention, relying on high-speed motion analysis[9-12,14-16,18] or electromyography (EMG) data.[13,17] However, these modalities are limited in producing accurate measurements due to challenges with motion capture in the setting of excessively high angular momentum of the throwing arm.

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Fig 1. The compression sleeve with the elbow torque device positioned 1.5 inches distal to the medial epicondyle.

Recently, a new elbow torque-measurement device ("ETD") was introduced with the purpose of quantitatively measuring torque/workload across the medial elbow during the throwing motion. This measurement is made using a gyroscopic sensor with an accelerometer that indirectly measures torque, as well as numerous other measurements (arm speed, arm slot, and shoulder rotation). Advantages of this device include significantly increased convenience for use in research and clinical applications, because the device is wearable on the thrower's elbow and transmits pitch data to a smartphone using a "smartphone app." This eliminates the need for sophisticated high-speed video analysis using markers or other such expensive setups and greatly increases the potential for widespread use in research purposes. The device has recently been validated when compared with the current gold standard of motion capture.[19] However, the device has not been studied in detecting "risk factors" for elevated torque production during the throwing motion in pitchers according to pitch type, pitch speed, and thrower demographic information, nor has its precision been studied. Therefore, the purpose of our study was to assess the precision of a new wearable device in detecting medial elbow torque during the pitching motion in competitive baseball pitchers and to determine the differences in torque across pitch types and thrower demographic characteristics. Our hypothesis was that the ETD would be precise in measuring torque on the medial elbow within any given player and pitch type, and that there would be higher forces detected in throwing breaking pitches when compared with throwing fastballs (FBs).

Methods

Institutional review board approval was granted for this study (Protocol number 10818). There was no external funding secured for this project, and there was no participation in the study by the manufacturer of the device. The device was paid for by the internal funds of the researcher's department, without any contact or participation by the vendor of the device. High school and collegiate baseball pitchers were recruited through direct request by athletic trainers and coaches. Inclusion criteria included baseball players whose primary position was pitcher and who were actively competing in a school or other league. Measurements were performed at various points in a player's season of competition. Exclusion criteria consisted of athletes who identified their primary position as being other than pitcher or those who were not actively competing in match play.

Each pitcher considered for the study completed an intake form detailing age, injury history, and the presence or absence of current injury to the throwing arm. Assessments were performed by 2 dedicated research assistants, who were senior medical students at the time of the study. A number of measurements were also collected for each thrower, including height, weight, body mass index, and throwing arm dimensions measured with the arm in neutral rotation. Total arm length was defined as the distance from the lateral aspect of the acromion to the most distal aspect of the fifth digit, upper arm length was defined as the distance from the acromion to the lateral epicondyle of the humerus, and forearm length was defined as the distance from the lateral epicondyle of the humerus to the styloid of the radius. Elbow circumference was also obtained by measuring the diameter around the medial and lateral epicondyles with the elbow in full extension.

The device used in this study was a gyroscopic sensor with an accelerometer (Motus Global, Massapequa, NY) placed in a wearable sleeve and positioned along the medial elbow. Before the recorded pitch session, pitchers were instructed to perform a throwing warm-up as they would before an actual game, without restriction to pitch number or pitch type. Pitchers were then instructed to select the appropriately sized sleeve for the ETD according to patient comfort. The sensor was placed in the allotted sleeve and positioned on the proximal forearm in accordance with the product instructions, placing the sensor approximately 1.5 inches distal to the medial epicondyle (Fig 1). The sleeves and devices were positioned by one of the 2 research assistants performing data collection and were periodically checked throughout the pitching session to ensure maintenance of position in the desired location.

The pitching session was conducted with the pitcher throwing from a mound toward a plate at a standard distance of 18.4 m. Directly behind the plate was a net with a defined strike zone. The pitching protocol was modified from a previously published article on pitching kinematics of various pitch types[1] and included 8 FBs, 8 curveballs (CBs), and 8 change-ups (CUs). A computer program randomized the order of pitches to create a standard sequence of pitches, and each pitcher

Table 1. Pitch Parameter Definitions

Pitch Parameter	Definition
Elbow torque	A measure of the peak torque placed on the medial elbow near the time of maximum shoulder rotation (N m)
Arm speed	The peak rotational velocity of the forearm (RPM)
Arm slot	The angle the forearm makes with the ground at release (degrees)
Shoulder rotation	The maximum angle that the forearm rotates back during the late-cocking phase (degrees)
Ball velocity	The peak velocity of the baseball from release to home plate (MPH)

MPH, miles per hour; RPM, rotations per minute.

followed this standard sequence to throw the same series of pitches. The pitchers were instructed to throw at maximum effort. The participants were given 30 to 60 seconds of rest between pitches, a technique previously shown to minimize fatigue and prevent variation in pitching mechanics.[20] The positioning of the sensor (in accordance with product instructions) was periodically assessed throughout the pitching session to confirm proper placement. Pitchers were instructed to report if they were experiencing fatigue or pain at any point in the study.

Data were recorded by the ETD and displayed and stored by the accompanying smartphone application by the manufacturer. For each pitch, the sensor reported torque across the medial elbow (defined as peak torque, in Newton-meters, measured indirectly with a gyrometer and accelerometer), arm speed (defined as peak rotational velocity of the forearm, in rotations per minute, or RPM), arm slot (defined as angle the forearm makes with the ground at release, in degrees), and shoulder rotation (defined as the maximum angle of the forearm during late cocking and just before moving forward for ball release, in degrees) (Table 1). For each pitch, the ball velocity measured in miles per hour (MPH) was also collected using a radar gun (Stalker Sport II radar gun, Stalker, Plano, TX). This radar gun was positioned directly behind the net and was used to capture peak ball velocity.

After the conclusion of the study, pitchers were provided an e-mail survey about their experience with the device.

Statistical Methods

All statistical analysis was performed using the statistical program Program R (www.r-project.org). Statistical analysis was performed by a PhD statistician, who was a member of the study team as well. Pitches were considered to be outliers and therefore excluded from analysis if they produced values of greater than 1.5 times the interquartile range either above the third quartile or below the first quartile using a boxplot. These pitches were typically caused by errors in detecting the pitch data to the smartphone app or to the radar gun. We assessed for differences in error number among pitch types using general linear models (*lm* function) in Program R. We used mixed-effects models conducted in Program R using the *lme* function to assess the influence of pitch type on stress, arm velocity, shoulder rotation, slot, and ball velocity. Because pitch type was nested within the pitcher (i.e., each pitcher threw 3 different pitches), the pitcher was used as the random effect and pitch type was the fixed effect in all models. We then used our demographic variables (age, height, weight, body mass index, total arm length, upper arm length, forearm length, elbow circumference) to explain the variation in stress, arm velocity, shoulder rotation, slot, and ball velocity when all pitch types were grouped together. General linear models were created using the function *lm*. Model selection was performed by exhaustive screening using the *leaps* function in Program R. Briefly, models were ranked according to their Bayesian Information Criteria value. The model with the lowest Bayesian Information Criteria value was selected as the best fitting model. We then used the Anova function and type II sums of squares to generate *F* statistics and *P* values for the best fitting model. We attained beta values for the best fitting model using SPSS (SPSS, Chicago, IL).

Results

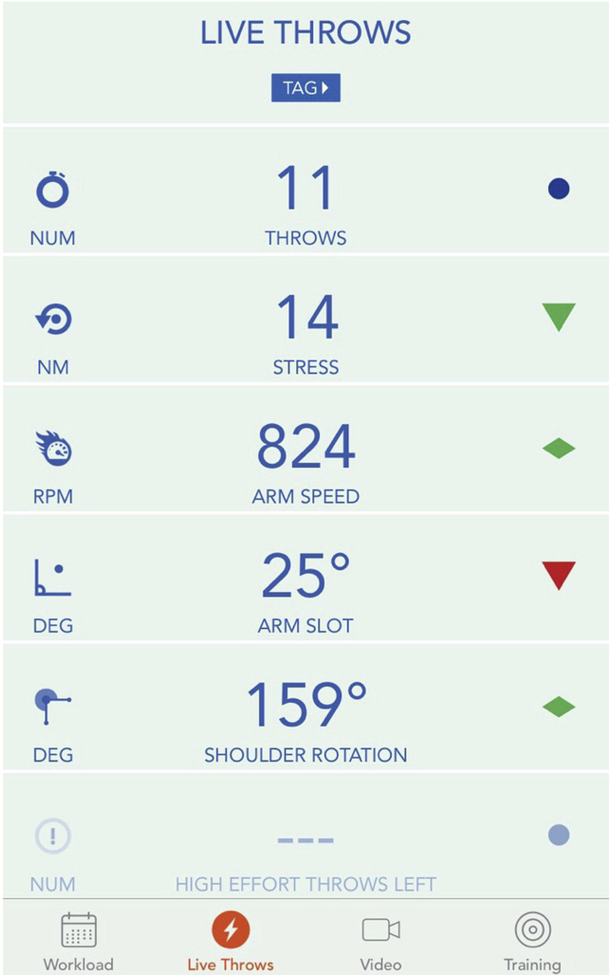
A total of 41 male baseball pitchers participated in this study. One pitcher was excluded because he had not pitched in over 2 years and was primarily a tennis player. Three other pitchers were excluded because of their sidearm pitching motion, which prevented the sensor and app from reliably collecting pitch data. In total, 37 competitive baseball pitchers were included in the study. The average age was 18.2 years (range, 16-20 years), and the average height was 186.4 cm (73.4 inches), range 174 to 196 cm (68.5-77.2 inches). Additional data regarding the pitchers can be found in Table 2.

There were no adverse events reported by the pitchers during the throwing sessions. All pitchers were able to fit into one of the designated arm sleeves without any irritation to the underlying skin. No

Table 2. Pitcher Demographics

Variable	Mean	SE	Range
Age, yr	18.2	0.2	16-20
Height, cm	186.4	0.9	174-196
Weight, kg	81.9	1.8	62-113
BMI	23.6	0.5	17.5-32.1
Total arm length, cm	77.1	0.5	71-84
Upper arm length, cm	34.2	0.3	31-37.5
Forearm length, cm	29.1	0.3	25.5-35.5
Elbow circumference length, cm	27.5	0.3	24.5-31

BMI, body mass index; SE, standard error.



LIVE THROWS

TAG ▸

11 THROWS (NUM) ●

14 STRESS (NM) ▼

824 ARM SPEED (RPM) ◆

25° ARM SLOT (DEG) ▼

159° SHOULDER ROTATION (DEG) ◆

--- HIGH EFFORT THROWS LEFT (NUM) ●

Fig 2. Sample output reading using the smartphone app of the device for a throw.

pitchers needed to alter their clothes (e.g., throw without a shirt) to accommodate the device. The device took approximately 6 to 70 seconds to apply by one of the research assistants. There were no acute malpositioning of the sleeve due to any of the pitch types thrown. A sample output from a pitch is seen in Figure 2.

To assess the precision of the device, the proportion of outlier pitches, compared with total number of pitches, was assessed with regard to the amount of torque measured for each pitch. The ETD accurately measured relative torque levels across all 3 pitch types (Fig 3). For FBs, the device accurately measured and recorded the data in 96.9% of pitches, compared with 96.9% for curve balls and 97.9% for CUs. In other words, of the 888 total pitches that were thrown in this study, only 23 pitches were considered outliers and not accurately measured. Outlier pitches were due to either a malfunction in the device, app, radar gun, or otherwise not identified.

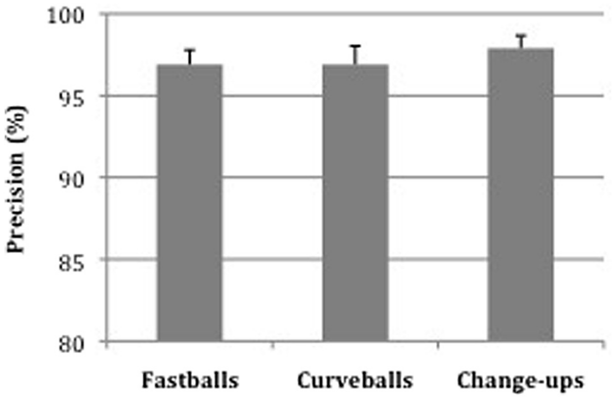


Fig 3. The elbow torque device was precise in measuring medial elbow torque for fastballs, curveballs, and change-ups. There was no significant difference in precision across pitch types ($P > .05$).

The ability of the ETD to detect differences in pitch parameters among pitch types (FB, CB, CU) was tested using mixed model regression analysis (Table 3). Therefore, the device was sensitive enough to distinguish pitches according to elbow torque, arm speed, arm slot, and shoulder rotation. Specifically, pitch type (FB, CB, and CU) was used to predict variation in elbow torque, arm speed, shoulder rotation, arm slot, and ball velocity (Table 4). Among the 3 pitch types, FBs caused the greatest torque on the medial elbow (average = 45.56 N m), compared with CUs (43.77 N m; $P = .006$) and CBs (43.83 N m; $P = .01$) (Fig 4). Arm slot angles were found to be greatest with CBs (54.4°; $P < .001$) when compared with FBs (51.01°) and CUs (50.76°). With regard to shoulder rotation, CUs (152°) were found to be less than FBs (154°; $P = .02$) and CBs (154°; $P = .01$). CBs produced the highest arm speed (856 RPM), compared with FBs (842 RPM; $P = .049$) and CUs (822 RPM; $P = .01$). Finally, FBs produced the highest ball velocity (75.0 MPH), compared with CBs (62.4 MPH) and CUs (67.6 MPH); both $P < .001$. The average variability for each pitch type in any given pitcher was 8.1 N m, 6.9 N m, and 7.3 N m for FBs, CBs, and CUs, respectively. Multiple regression analysis indicated that player height was the best predictor for the increase in variability, such that shorter pitchers had higher variability within any pitch type.

In addition, multiple regression analysis was performed to determine which variables most significantly predicted torque on the medial elbow, as well as for

Table 3. The ETD Was Able to Detect Significant Differences Among Pitch Types for Torque, Arm Speed, Arm Slot, and Shoulder Rotation

Pitch Parameter	*F*	DF	Significant Differences Among Pitch Types (*P* Value)
Elbow torque	4.891	2.72	.01
Arm speed	10.743	2.72	<.001
Arm slot	11.913	2.72	<.001
Shoulder rotation	3.728	2.72	.028
Ball velocity	269.6	2.72	<.001

DF, degrees of freedom; ETD, elbow torque device; *F*, f value.

Table 4. Pitch Parameter Results for Fastballs, Curveballs, and Change-ups, as Measured by the ETD and Radar Gun

	Elbow Torque, N m	Arm Speed, RPM	Arm Slot, deg	Shoulder Rotation, deg	Ball Velocity, MPH
Fastballs	45.6 ± 1.0 (23-70)	842.4 ± 11.4 (601-1,138)	51.0 ± 2.1 (26-78)	154.1 ± 2.2 (121-312)	75.0 ± 0.9 (63-88)
Curveballs	43.8 ± 0.9 (23-62)	855.7 ± 11.8 (601-1,138)	54.4 ± 2.4 (23-81)	154.4 ± 2.3 (122-183)	62.4 ± 0.8 (50-80)
Change-ups	43.8 ± 1.0 (22-64)	822.0 ± 12.8 (609-1,083)	50.8 ± 2.1 (28-82)	152.2 ± 2.3 (117-183)	67.6 ± 0.8 (54-86)

NOTE. All data are reported as mean ± standard error (min-max).
ETD, elbow torque device; MPH, miles per hour; N m, newton meters; RPM, rotations per minute.

arm speed, arm slot angle, shoulder rotation, and ball velocity (Table 5). Ball velocity and elbow circumference were found to be the best predictors of elbow torque, where higher ball velocity and smaller elbow circumference predicted higher medial elbow torque. Weight was found to be the best predictor of arm speed, where lighter pitchers had faster arm speeds. Greater arm slot angles were found in pitchers with smaller elbow circumferences. With regard to shoulder rotation, shorter pitchers were found to have greatest shoulder rotation. Finally, ball velocity was best predicted by high elbow torque, elevated shoulder rotation, and heavier weight.

An exit survey was e-mailed to all participants regarding their experience using the elbow sensor. These results can be found in Table 6. According to this survey, importance of monitoring elbow kinematics is clearly shown, as is willingness to use the device in a practice (but not competition) setting.

Discussion

The results from this study indicate that the ETD is a precise and reproducible device for measuring torque on the medial elbow. Moreover, increased torque across the medial elbow was found in FBs, as opposed to breaking pitches such as CBs and CUs. Results from the multiple regression models indicate that velocity is the chief determinant of torque across the medial elbow in this group of competitive male baseball pitchers. These results may aid in better understanding risk factors for developing overuse injury in this at-risk athletic population.

Numerous different technologies have been used to measure torque and kinematics across the elbow during the pitching motion. All of these devices indirectly measure stress and torque on the medial elbow, because direct measurement is challenging due to the dynamic nature of the throwing motion. These devices include EMG as well as high-speed video motion analysis (both with markers and marker-less). Similar to these modalities, the ETD used in this study does not directly measure torque because it is indirectly measured using a gyroscope and accelerometer. Consequently, the actual output value does not matter so much as the ability to use the device as a precise tool for measuring *relative* torque. Moreover, much of the high-speed motion analysis research (which is widely cited and referenced) of the throwing motion has been focused on detecting changes in throwing kinematics as a function of fatigue, age, or experience level of the pitcher.[12,16] In addition, the device indirectly measures additional parameters of shoulder rotation, arm speed, and slot angle. One of the main advantages of this device is that it is relatively easy and convenient to use, as compared with sophisticated motion analysis and EMG systems that require elaborate setups. Therefore, successful validation of this device may have the potential to improve kinematic research of the throwing motion in overhead athletes.

The principal finding from this study is that the ETD is a highly precise and sensitive device. Of the 888 pitches thrown in this study, only 23 (2.6%) were considered outliers. Therefore, assuming consistent pitch mechanics and effort, the device (and setup used in this study) can be useful in collecting data on 97.4% pitches thrown by a given player. Moreover, this precision indicates that—within the confines of this pitching session—competitive pitchers are highly reproducible in their mechanics with regard to forces across the elbow according to a given pitch type. There has been one recent study[19] that did validate the device using motion capture technology. The authors of that study reported "good to excellent" correlation between the wearable device and motion capture assessment across a number of parameters (elbow varus torque, arm rotation, arm speed, and arm slot). Although this study did include a higher number of pitchers and pitch counts (81 pitchers with 82,000 throws), it did not

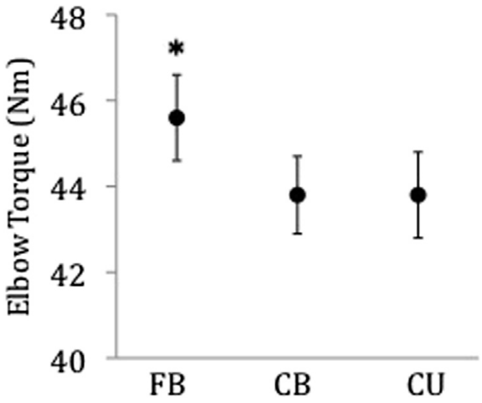


Fig 4. Effect of pitch type on elbow torque. Fastballs (FBs) produced significantly more torque on the medial elbow than curveballs (CB, $P = .006$) and change-ups (CU, $P = .01$). Significant differences are denoted with an asterisk.

Table 5. Variables That Best Predict Pitch Parameters After Performing Multiple Regression Analysis

Pitch Parameter	Predictor Variable	Model Coefficient	β	*T*	*P*
Elbow torque	Ball velocity	0.224	0.277	3.000	.003
	Elbow circumference	−0.811	−0.217	−2.353	.021
Arm speed	Weight	−1.794	−0.277	−3.035	.003
Arm slot	Elbow circumference	−3.538	−0.430	−4.975	<.001
Shoulder rotation	Height	−0.501	−0.192	−2.039	.043
Ball velocity	Torque	0.328	0.272	3.048	.003
	Shoulder rotation	0.129	0.239	2.705	.008
	Weight	0.176	0.253	2.828	.005

assess the impact of pitch type (FB, CB, CU), pitch speed, or thrower demographics on the amount of torque produced, which was a significant advantage of our study.

The second important finding in this study is that FBs—and not CBs or CUs[8,9]—produce the highest torque on the medial elbow. This is reinforced by the findings of the regression model that state that pitch velocity is the most significant contributor to torque across the medial elbow. This corroborates the findings of several recent studies[5,12,14-16,21,22] that used indirect means to determine that breaking pitches may not produce more torque across the elbow when compared with FBs. This includes the use of three-dimensional or computational analysis of high-speed video motion capture[12,14-16,21] or injury history with cross-reference to historical pitch types thrown.[5] In comparison, our study provides relative quantitative torque measurement data across 3 different pitch types. Most importantly, however, the device and testing setup used in our study requires a fraction of the costs required for a motion capture system or an EMG system. The retail cost of the device is $149.99 (as of time of manuscript preparation). Interestingly, pitchers in this study showed an interest and willingness to use this device in a practice setting, thereby further increasing the potential impact of this device as a practical tool for clinical and research applications.

The multiple parameters (in addition to torque) indirectly measured by the ETD—shoulder rotation, arm speed, and slot angle—do provide additional details with regard to the impact of pitcher body type on throwing kinematics. For example, decreased elbow circumference contributed to increased torque levels during pitching. This would seem to be a logical finding, because the decreased area of force distribution would lead to higher stress. In addition, lighter pitchers were found to have higher arm speeds, indicating that this increase in speed compensated for decreased force due to lighter body weight. Finally, shorter pitchers were found to have greater shoulder rotation, indicating increased shoulder external rotation in late cocking before beginning forward motion for ball release.

Limitations

This study does have important limitations. It is impossible to determine if the torque measured across the medial elbow during the throwing motion is a true measure of stress across the elbow UCL during pitching. More reasonably, it represents an aggregate sum of force across the medial elbow during the throwing motion. It is also important to note that these measurements are made using gyrometers and accelerometers, and are therefore indirectly measured. However, the relative values are useful in the clinical and research settings, and are reliably measured using this device as shown in this study. To determine how accurately the device measures torque across the UCL, a cadaver study could be designed. However, such a study would disregard important primary and secondary stabilizers of the elbow joint during the dynamic throwing motion. Therefore, although not a perfect measure of UCL stress, the ETD used in this study does have the potential to at the very least measure medial elbow torque relatively. Such a capability provides valuable clinical and research applications, because the device may be used to determine the relative impacts of secondary variables (i.e., fatigue, injury, recovery from treatment, etc.) on torque across the medial elbow during throwing. Unfortunately, we do not know if the differences in torque produced represent a minimal

Table 6. Pitcher Responses to Follow-up Questionnaire

Survey Question	Yes	No
Do you think it is important to monitor the stress placed on your throwing arm?	21 (95%)	1 (5%)
Do you think the ETD and compression sleeve negatively impact your throwing performance?	1 (5%)	21 (95%)
Would you use the ETD and compression sleeve in a practice setting?	20 (91%)	2 (9%)
Would you use the ETD and compression sleeve in a game setting?	9 (41%)	13 (59%)
Do you think you would adjust your throwing motion based on your results?	16 (73%)	6 (27%)

ETD, elbow torque device.

clinically important difference across the pitch types. We can state, however, that the breaking pitches did not produce more torque than FB counterpart pitches when controlling for other parameters. Secondly, as pitchers aged 16-20 were used in this study, we are unable to state whether the findings of increased torque with FBs (as opposed to breaking pitches) hold true in the youth and adolescent patient population. A secondary study in this patient population will be beneficial in determining this result. Moreover, the study employed a low number of pitches (24) in a simulated pitching session. Therefore, it is impossible to determine whether these findings would be reproducible in "real" competition environments. Finally, as the results of the exit survey suggest, pitchers are unlikely to adopt the use of the sleeve during real, in-game competition. This may pose limitations for future adoption of the device into competition environments.

Conclusions

The sensor is a precise and reproducible device for measuring torque across the medial elbow, as well as additional parameters of arm speed, arm slot, and shoulder rotation. Torque was significantly relatively higher in FBs than CBs and CUs.

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