Youth Pitcher Fatigue

Medial Elbow Laxity, Ultrasonographic Assessment of Flexor-Pronator Mass Energy Depletion, and Association With Pitch Count

Manuel F. Schubert,[*†] MD, MS, Tariq M. Awan,[*‡] DO, Aaron D. Sciascia,[§] PhD, ATC, PES, SMTC, FNAP, Emily G. Figueroa,[*] MS, Jennifer M. DeMink,[*] PT, DPT, OCS, David M. Selak,[*] PT, DPT, OCS, Corey M. Snyder,[*] PT, DPT, OCS, SCS, MTC, CSCS, Joel J. Gagnier,[*||¶] PhD, ND, MSc, and Michael T. Freehill,[*#**] MD

Investigation performed at the University of Michigan, Ann Arbor, Michigan, USA

Background: Ulnar collateral ligament (UCL) injuries in youth pitchers continue to be concerning despite the institution of pitch count limits. Flexor-pronator mass fatigue can lead to diminished dynamic stability, resulting in greater stress on the UCL.

Purpose/Hypothesis: To evaluate fatigue of the flexor-pronator mass by assessing changes in medial elbow laxity; noninvasively characterizing alterations in muscle glycogen; and identifying changes in subjective fatigue, strength, range of motion (ROM), pitching velocity, and accuracy with increasing pitches thrown by youth pitchers to their recommended 75-pitch count limit. It was hypothesized that, with increased pitches, medial elbow laxity would increase and that the glycogen content of the flexor-pronator mass would decrease.

Study Design: Descriptive laboratory study.

Methods: Healthy male pitchers aged 10 years (n = 22) threw 3 sets of 25 pitches with 12 minutes between sets (3 timepoints). Bilateral ulnohumeral joint gapping was measured by applying a standardized valgus force and utilizing ultrasound imaging. Relative changes in muscle glycogen in the bilateral flexor carpi radialis (FCR), and the flexor digitorum superficialis/flexor carpi ulnaris (FDS/FCU) muscles were measured with ultrasound software and recorded as fuel percentiles. Additional measures obtained included subjective fatigue, strength, ROM, velocity, and accuracy.

Results: There were no differences in medial elbow joint-line gapping between the throwing and nonthrowing arms or between timepoints. The throwing arm demonstrated a significant decline in fuel percentile of the FCR from baseline to after 75 pitches (P = .05). There were no differences across timepoints for FDS/FCU fuel percentile values. Fatigue measurements for both arms were significantly higher at all timepoints compared with baseline ($P \leq .03$). Grip strength of the dominant arm after 75 pitches was decreased significantly compared with after 25 pitches (P = .02).

Conclusion: Although an increase in medial elbow joint gapping was not demonstrated within the recommended 75 pitch count limit in 10-year-olds, a relative decrease in glycogen stores of the flexor-pronator mass did occur, as well as a decrease in grip strength, with increasing subjective fatigue.

Clinical Relevance: This study provides a foundation for further objective testing of physiologic changes that occur with pitching to better guide pitch count limits and improve the safety of young athletes.

Keywords: elbow; fatigue; glycogen; pitch counts; pitching; ulnar collateral ligament

Throwing injuries, particularly common in overhand pitchers, occur at all levels of competition and have reached epidemic proportions.[8,12,24] Pain and injury are now common occurrences, even among youth and adolescent players.

The Orthopaedic Journal of Sports Medicine, 12(6), 23259671241256294
DOI: 10.1177/23259671241256294

Approximately 18% to 22% of American Little League pitchers report elbow pain.[16,23,26] Others have reported the incidence of elbow pain in youth throwers to be 20% to 30% for 8- to 12-year-olds, 45% for 13- to 14-year-olds, and >50% for high school and collegiate players.[15,25,26,37]

There has been a recent rise in elbow ulnar collateral ligament (UCL) injuries in youth pitchers. Between 2006 and 2016, the incidence of elbow injuries in youth baseball players increased despite the overall incidence of baseball injuries decreasing.[37] This is exacerbated exponentially by the rising trend of early sports specialization.[10,22,33,34,37] Increased pitching workload may be associated with an increased risk of pain, injury, and arm fatigue in Little League and high school pitchers.[3] The likelihood of injury in youth pitchers is 3.5 times higher if they throw more than 100 innings a year.[12] Players who throw through fatigue and pain have more than 7 times the odds of sustaining a pitching-related injury,[40] and a youth pitcher who regularly pitches despite arm fatigue is at 36 times higher risk of injury.[30]

As the dynamic stability of the forearm flexor-pronator mass diminishes with increased muscle fatigue, it could be reasoned greater stress would be borne by the UCL. Thus, the UCL could be at heightened risk in the setting of more pitches and flexor-pronator mass fatigue. Pitch count limits have been instituted in an attempt to help curtail this rise in throwing injuries, especially in youth athletes. There remains a paucity of data and understanding of the process of muscle fatigue in the flexor-pronator mass of throwing athletes, and the subsequent potential for increased laxity of the medial elbow joint. Recent novel advancements in ultrasound technology allow for the ability to determine relative amounts and changes in energy storage via glycogen content in select muscles.[20,28]

To provide more objective data regarding current pitch count limits for youth pitchers, we aimed to evaluate changes in medial elbow joint-line laxity with respect to noninvasive characterization of changes in muscle energy storage from the forearm flexor-pronator mass. An additional purpose was to evaluate changes in fatigue, strength, range of motion (ROM), pitching velocity, and accuracy with increasing pitches thrown by 10-year-old baseball players up to their recommended 75 pitch-count limit. Our hypothesis was that with increased pitches, medial elbow laxity would increase and that the glycogen content of the flexor-pronator mass would decrease.

METHODS

Participants

Institutional review board approval was obtained for the study protocol. Competitive travel baseball players 10 years of age who pitched for their teams were eligible for this study (ie, there were no "pitcher-only" participants included). Players with previous shoulder or elbow injuries were allowed to participate if they had since been able to return to play without restrictions. Players with active injuries for which they were undergoing treatment or requiring rest from athletics were excluded. We excluded players with a history of elbow or shoulder surgery. The study was performed in the winter months leading into the spring season but not during a competitive season. Players provided assent and parents provided informed consent for participation in the study.

Testing

During testing, players were allowed to drink water for hydration but were asked to avoid consumption of carbohydrate-replenishing drinks. The pitching protocol instituted was designed to simulate a game scenario, including warm-up pitches and specified rest in between pitches. Pitching was performed indoors from a mound in a sports performance center. The pitching setup is demonstrated in Figure 1.

Before pitching, baseline bilateral shoulder and elbow ROM measurements were obtained with a goniometer. Measurements obtained included bilateral supine internal and external rotation at 90° of abduction as well as bilateral elbow flexion and extension. Baseline bilateral shoulder strength measurements were obtained with participants standing with a handheld digital dynamometer (microFET2; Hoggan Scientific) in pounds of pressure. Shoulder strength measurements consisted of supraspinatus testing

**Address correspondence to Michael T. Freehill, MD, Department of Orthopaedic Surgery, Stanford University School of Medicine, 450 Broadway Street, Redwood City, CA 94063, USA (email: freehill@stanford.edu).

*Department of Orthopaedic Surgery, University of Michigan, Ann Arbor, Michigan, USA.

†Department of Orthopaedic Surgery, Detroit Medical Center, Detroit, Michigan, USA.

‡Ascension Medical Group Beacon Orthopaedics of Michigan, Novi, Michigan, USA.

§Institute for Clinical Outcomes and Research, Lexington Clinic, Lexington, Kentucky, USA.

||Department of Epidemiology, School of Public Health, University of Michigan, Ann Arbor, Michigan, USA.

¶Department of Epidemiology and Biostatistics, Western University, London, Ontario, Canada.

#Department of Orthopaedic Surgery, Stanford University School of Medicine, Redwood City, California, USA.

Final revision submitted September 30, 2023; accepted November 13, 2023.

One or more of the authors has declared the following potential conflict of interest or source of funding: funding for this study was provided by the University of Michigan. M.F.S. has received education payments from Arthrex and Smith+Nephew and hospitality payments from Stryker and Medical Device Business Services. T.M.A. has received education payments from Fujifilm SonoSite, consulting fees from Arthrex, nonconsulting fees from Arthrex, and honoraria from Tenex Health. M.T.F. has received grant support from Encore Medical; education payments from Evolution Surgical; consulting fees from Biorez, Smith+Nephew, and Stryker; nonconsulting fees from Smith+Nephew and Integra LifeSciences; royalties from Smith+Nephew; and hospitality payments from Xiros and Wright Medical. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was obtained from the University of Michigan (ref No. HUM00135428).

Figure 1. Pitching setup for the study, including mound (at the back of the room) and pitching target with simulated strike zone (netted square in foreground).

with the thumbs-up variation of the Jobe test described as the “full can” position,[21] external rotation with the arm in neutral and external rotation at 90° of shoulder abduction and 90° of elbow flexion. Baseline bilateral grip strength in pounds of pressure was measured with a digital hand dynamometer (Jamar Plus + ; Sammons Preston) with participants standing and their elbows flexed to 90° and shoulders adducted to neutral. Final measurements for shoulder and grip strength at each timepoint were the mean of 3 consecutive repetitions for each variable. Baseline and time interval perceived fatigue of bilateral upper extremities was obtained utilizing a modified Borg scale,[5,29] ranging from 0 (no fatigue) to 10 (maximal fatigue).

Ultrasound Imaging. Ultrasound imaging was performed by an experienced ultrasonographer (T.M.A.). The forearm was placed in a resting position with the elbow in flexion and the forearm in supination (Figure 2A). The proximal aspect of the forearm flexors was then imaged with a Philips Lumify 12-4 MHz linear ultrasound transducer (Philips Healthcare). The location of the transducer was centered over the flexor carpi radialis (FCR) muscle in order for the cloud-based software (MuscleSound; MuscleSound) to recognize and analyze muscles based on their imaging processing algorithms. To obtain reproducible images, the ultrasound transducer was placed in line with the axis spanning from the medial epicondyle of the elbow to the radial styloid. A line was then marked the length of 1 transducer from the medial epicondyle along this axis. The transducer was then oriented perpendicular to this axis to visualize the muscles on their short axis. The transducer was translated distal and radial or proximal and ulnar to center the septa around the FCR which appeared as a “V” on the ultrasound (Figure 3). Three images were then captured at this location. Maintaining the same orientation, the transducer was then translated slightly distal and ulnar to center the transducer along the flexor digitorum superficialis (FDS) and flexor carpi ulnaris (FCU) to capture 3 images of these forearm flexors. This process was repeated on the contralateral arm. The images of the forearm flexor muscles were then transmitted to the secure cloud-based application for imaging processing to determine the relative muscle glycogen content.

Bilateral baseline and stress medial ulnohumeral joint distances were then measured with a linear 12-MHz transducer on a standard diagnostic GE LOGIQ-e ultrasound machine (GE Healthcare). Each player was seated with the elbow positioned at 30° of flexion while placed in a standardized stress device (Telos SD 900; Telos Medical USA) without any stress applied (Figure 2B). The ultrasound

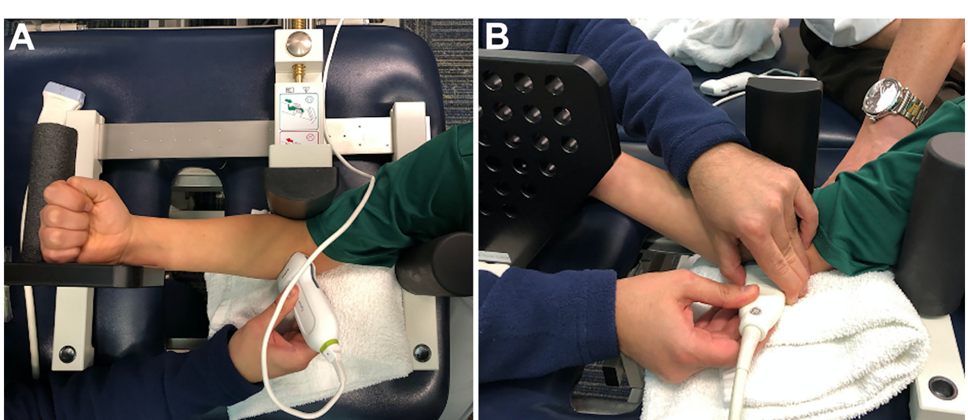

Figure 2. (A) Top view of position of forearm and location of ultrasound probe to identify flexor-pronator mass for glycogen storage evaluation. (B) Setup of standardized stress device and location of ultrasound transducer to measure medial ulnohumeral joint distance.

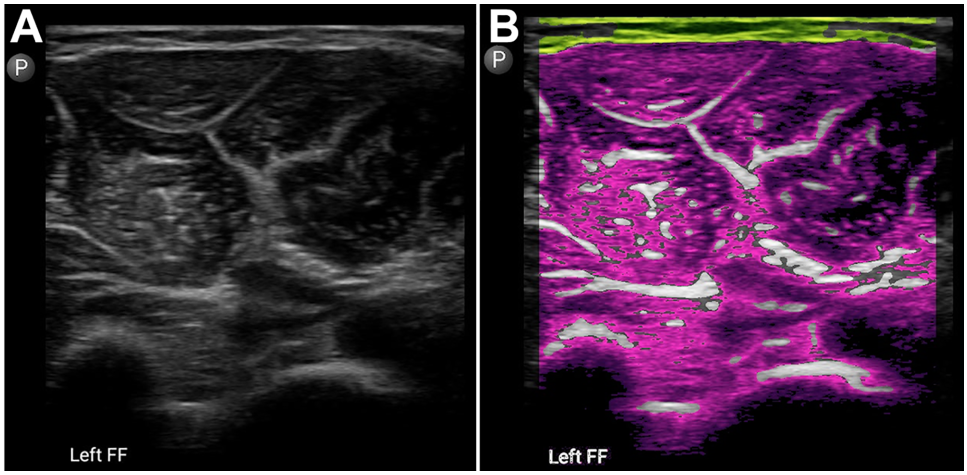

Figure 3. (A) Sample ultrasound image collected of the left forearm flexor (FF) focused on the flexor carpi radialis (FCR) muscle belly for glycogen storage processing. (B) Sample FCR ultrasound image processed with cloud-based software. Pink/purple, identified muscle used in scoring energy storage; green/yellow, adipose/muscle boundary and superior skin border; gray/white/black, nonscored tissue.

transducer was positioned along the medial ulnohumeral joint to visualize the joint at the location of the UCL (Figures 2B and 4). To evaluate the changes in medial ulnohumeral joint distance (ie, medial elbow laxity) as stress was applied to the UCL, 10 decanewtons (daN) of force were applied across the elbow while at 30° of flexion, and the joint distance was measured on the ultrasound image (Figure 4).[2,6,7]

Pitching. After baseline testing was completed, study participants performed warm-up throws of easy effort for 5 minutes from a distance of 30 to 40 feet (9.1-12.2 m) on flat ground. After this warm-up period, they entered the pitching area, which consisted of a prefabricated pitching mound that was placed the Little League pitching distance of 46 feet (14 m) from the fabricated strike zone (Figure 1). The strike zone width was set at 17 inches (43 cm) to replicate the width of home plate. The superior border of the strike zone was set to the midpoint between the pitcher's shoulders and top of the pants. The inferior strike zone border was set to just below bilateral patellae. Any pitches that were thrown within or hit the edges of the strike zone were counted as strikes. The rest were counted as balls. Pitchers only threw fastballs for consistency.

Before data collection, pitchers threw 6 warm-up pitches from the mound. Pitchers then proceeded to throw a set of 25 pitches. To standardize the amount of time required for the pitching assessment and reduce variability in pitching time, players waited 20 seconds to initiate the wind-up for their next pitch after the previous pitch was thrown. This was based on the 20-second pitch timer instituted by Minor League Baseball as part of their pace-of-game initiatives. Accuracy for each set of 25 pitches thrown was determined as the percentage of strikes thrown for that set. Velocity of each pitch was measured in miles per hour (mph) with a radar gun (Stalker Pro II; Stalker Radar).

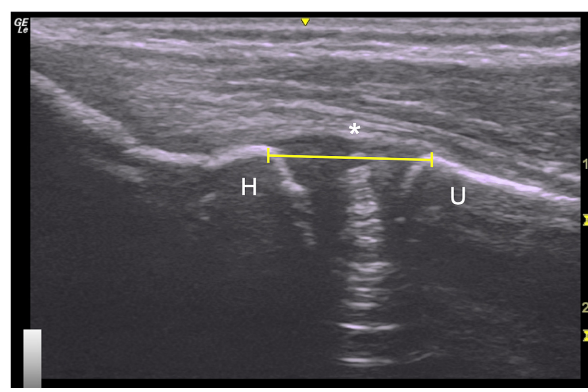

Figure 4. Sample ultrasound image to measure medial ulnohumeral joint distance. A measurement bar was superimposed to demonstrate the location of measurements taken on the ultrasound device. Measurements were taken at the apex of the ossified portion of the humeral and ulnar epiphysis. When the ossified portion of the epiphysis was less defined, but the edge of the cartilaginous epiphysis was more clearly defined, then the apices of the humeral and ulnar epiphyses were used for a given subject. A single method was used per subject for consistency within that subject's measurements to measure the change in medial ulnohumeral joint distance. The asterisk indicates longitudinal fibers of the UCL, and the yellow bar indicates the ulnohumeral joint distance. H, humerus; U, ulna; UCL, ulnar collateral ligament.

After completion of the 25 pitches, pitchers who underwent all of the testing and measurements that were obtained at baseline for their bilateral upper extremities as described above, except medial ulnohumeral joint distance without stress applied was not performed after pitching. There was a minimum 12-minute break during which these various measurements and imaging were performed before returning to throwing to ensure an adequate period of rest. After this, pitchers returned to throwing, consisting of the 6 warm-up pitches and the 25 recorded pitches. Testing after the 25 pitches was repeated as before. A final set of 25 pitches was then thrown as before for a total of 75 recorded pitches. The final set of imaging and measurements were obtained thereafter. Timepoints for data analysis were designated as baseline (before pitching) and then sequentially as timepoints 1 (pitches 1-25), 2 (pitches 26-50), and 3 (pitches 51-75).

Data Analysis

Medial ulnohumeral joint distance was measured on the ultrasound images as the distance from the apex of the ossified portion of the humeral and ulnar epiphyses. All measurements were made by the same 2 study members (M.F.S. and T.M.A.). When the ossified portion of the epiphysis was less defined but the edge of the cartilaginous epiphysis was defined more clearly, then the apices of the humeral and ulnar epiphyses were used for a given player. Because the outcome of concern was change in medial elbow laxity with stress applied, a single method was used per subject for consistency within that subject's measurements to accurately measure the change in medial ulnohumeral joint distance, which was thereby standardized regardless of the locations used to measure absolute joint distance. The change in medial ulnohumeral joint distance after stress was applied was calculated from baseline without stress.

Relative changes in muscle glycogen storage, detected as changes in echogenicity, in the FCR, and in thecombined FDS and FCU (FDS/FCU) were recorded as fuel percentile. Details of how the proprietary cloud-based software processes the ultrasound images can be found in previous validation studies.[20,28] Briefly, the software determines the mean pixel intensity per group of 3 images and uses this to determine the relative glycogen storage of a given muscle based on the water content associated with the glycogen present in the muscle. Ultrasound images are hypoechoic in the presence of increased glycogen content due to the increased presence of water, whereas images are more hyperechoic in the presence of glycogen depletion and, thereby, water loss.[28] Conversion of the muscle echogenicity data to fuel percentile values allowed for a standardized assessment of relative changes between pitchers and between timepoints. This variable allowed for the ability to compare the energy status of muscles based on relative echogenicity with that of a larger population of muscle ultrasound images included in the secure cloud-based database of scans. At the time of the analysis, there were a total of 786 participants with 2783 total forearm flexor ultrasound images in the database. The echogenicity of the images obtained in the current study were compared with those images in the database to generate the fuel percentile scores. Changes in echogenicity, a proxy measure for relative changes in glycogen storage based on water content, were then reported as changes in the fuel percentile score to standardize the value.

Means and standard deviations were determined for all variables. The distribution of data for each variable were determined to be normal as assessed by the Shapiro-Wilk test. Repeated measures analyses of variance were used to analyze within and between arm measurement differences for all variables across the 4 timepoints (baseline and postpitching after 25, 50, and 75 pitches). The Mauchly test was utilized to assess sphericity. In the event sphericity had been violated, a Greenhouse-Geisser correction was employed. The Bonferroni method was used for post hoc analysis as appropriate. The threshold for statistical significance was set at $P \leq .05$. All analyses were performed via SPSS (Version 26; IBM).

Power Analysis

Power analysis was based on the 2 previous validation studies of the ultrasound cloud-based technology which included 20 and 22 participants.[20,28] On the basis of this previous research, for the ultrasound processing technology, Hill et al[20] stated a prescore of 59.8. Based on the 0 to 100 scale of the processing software's glycogen quantification, a postscore of 39.8, a common standard deviation of 11.24, $\beta = 0.80$, and an $\alpha = 0.05$, we obtained a required sample size of 5 using the paired t test. Therefore, we expected sufficient power to detect a $\geq$20 point change on the 0 to 100 scale in the results of the muscle glycogen test. There were no standard deviations or variability data available from previous studies to use for the sample size calculation; thus, we were forced to use this rule of thumb. The previous studies used a relative score that ranged from 0 to 100, while we used the standardized value of fuel percentile to better allow for comparisons between pitchers and between timepoints. Although previous studies did not use this percentile value in their analysis, we used the above available data to help guide our power analysis. Therefore, we planned to include a convenience sample of 22 athletes in this pilot study. This is well above the number of participants needed based on the sample-size calculation.

Although our primary outcomes consisted of both the change in medial ulnohumeral joint gapping and the change in relative muscle glycogen storage with increased pitching, we based our power analysis on changes in relative glycogen storage via the ultrasound image processing software as this would be the variable we expected to see more prominent changes. Furthermore, as Hattori et al[18] had previously reported increased medial elbow valgus laxity immediately after repetitive pitching, we felt the power was better determined based on flexor-pronator glycogen changes.

RESULTS

A total of 22 athletes were enrolled in and completed the study. Table 1 provides baseline characteristics of the

TABLE 1
Baseline Characteristics of the Study Group (N = 22 players)[a]

Variable	Value
Age, y	10 ± 0
Height, cm	144.1 ± 5.31
Weight, kg	36.7 ± 4.26
Throwing arm	
Right	21 (95.45)
Left	1 (4.55)

[a]Data are reported as mean ± SD or N (%).

TABLE 2
Change in Medial Elbow Laxity at Each Timepoint[a]

	Δ Medial Elbow Laxity, mm		
Timepoint[b]	Throwing	Nonthrowing	*P*
Baseline	0.6 ± 0.6	0.5 ± 0.4	.44
Timepoint 1	0.7 ± 0.7	0.5 ± 0.5	.23
Timepoint 2	0.8 ± 0.8	0.6 ± 0.4	.34
Timepoint 3	0.9 ± 0.8	0.7 ± 0.5	.42

[a]Data are reported as mean ± SD. The change in medial elbow laxity was calculated as the medial ulnohumeral joint distance with stress applied minus the joint distance without stress (at rest). Triangle indicates 'change in'.

[b]Timepoint 1, after pitches 1-25; timepoint 2, after pitches 26-50; timepoint 3, after pitches 51-75.

TABLE 3
Fuel Percentile Values for the FCR and FDS/FCU at Each Timepoint[a]

Timepoint[b]	Throwing	Nonthrowing	*P*
FCR fuel percentile			
Baseline	26.8 ± 26.3%**	25.2 ± 20.2%	.82
Timepoint 1	17.8 ± 14.8%	18.7 ± 13.7%	.83
Timepoint 2	13.5 ± 15.1%	15.9 ± 13.5%	.57
Timepoint 3	16.3 ± 17.4%	15.4 ± 13.3%	.86
FDS/FCU fuel percentile			
Baseline	15.2 ± 17.9%	26.6 ± 26.9%	.14
Timepoint 1	22.7 ± 23.6%	8.6 ± 6.5%	**.01**
Timepoint 2	13.8 ± 16.9%	15.3 ± 14.1%	.75
Timepoint 3	17.7 ± 17.1%	13.9 ± 14.6%	.43

[a]Data are reported as mean ± SD. Boldface *P* value indicates statistically significant difference between throwing and nonthrowing arms ($P \leq .05$). FCR, flexor carpi radialis; FDS/FCU, flexor digitorum superficialis/flexor carpi ulnaris.

[b]Timepoint 1, after pitches 1-25; timepoint 2, after pitches 26-50; timepoint 3, after pitches 51-75.

**Significantly greater compared with timepoint 3 for the throwing arm ($P = .05$).

TABLE 4
Subjective Fatigue Measurements Before Pitching and After Each Set of 25 Pitches[a]

	Subjective Fatigue (0-10 scale)		
Timepoint[b]	Throwing	Nonthrowing	*P*
Baseline	0.48 ± 0.87*	0.41 ± 0.55*	.76
Timepoint 1	1.6 ± 1.2**†	0.80 ± 0.78†	**.009**
Timepoint 2	2.6 ± 1.3	1.3 ± 1.3	**.002**
Timepoint 3	3.4 ± 1.7	1.5 ± 1.4	**.001**

[a]Data are reported as mean ± SD. Boldface *P* values indicate statistically significant difference between throwing and nonthrowing arms ($P \leq .05$).

[b]Timepoint 1, after pitches 1-25; timepoint 2, after pitches 26-50; timepoint 3, after pitches 51-75.

*Significantly less fatigue compared with all other timepoints ($P \leq .03$).

**Significantly less fatigue compared with timepoint 2 ($P = .001$)

†Significantly less fatigue compared with timepoint 3 ($P \leq .02$).

study group. All participants were 10 years old at time of the study. All but 1 of the pitchers threw with the right arm. Three of the pitchers (13.6%) reported a history of pain or soreness in their throwing arm (2 elbow, 1 general arm) 1 to 2 years before the study, with complete resolution of symptoms.

There were no significant differences regarding change in medial elbow laxity between the throwing and nonthrowing arms (Table 2) or between individual timepoints ($P \geq .459$). The mean increase in the medial ulnohumeral joint distance of the throwing elbow with stress applied versus at rest was 0.6 mm at baseline, 0.7 mm at timepoint 1, 0.8 mm at timepoint 2, and 0.9 mm at timepoint 3. For the nonthrowing elbow, with stress applied the medial ulnohumeral joint distance increased a mean of 0.5 mm at baseline, 0.5 mm at timepoint 1, 0.6 mm at timepoint 2, and 0.7 mm at timepoint 3 (Table 2).

There was a trend toward a similar decline in FCR fuel percentile values between arms, indicating relative decreases in glycogen storage bilaterally (Table 3). However, only the throwing arm demonstrated a statistically significant decline in fuel percentile from baseline (26.8% ± 26.3%) to after 75 pitches (16.3 ± 17.4%) ($P = .05$). There were no additional statistically significant differences across timepoints or between the throwing and nonthrowing arms for the FCR fuel percentile values. There were no statistically significant differences across timepoints for the FDS/FCU fuel percentile values in the throwing and nonthrowing arms (Table 3). The FDS/FCU fuel percentile value was significantly lower in the nonthrowing arm compared with the throwing arm after 25 pitches (timepoint 1) ($P = .01$). There were no additional statistically significant differences between arms in the FDS/FCU fuel percentile values.

Subjective fatigue at baseline before pitching for both arms was statistically lower compared with all other timepoints ($P \leq .03$) (Table 4). Subjective fatigue in the throwing arm after the first 25 pitches (timepoint 1) was significantly lower than after throwing the second set and third set of pitches ($P = .001$ and $P \leq .02$, respectively). In the nonthrowing arm, subjective fatigue after the first

TABLE 5
Strength Measures Across Timepoints[a]

Timepoint[b]	Strength Measure, Pounds (kg) of Pressure: Throwing	Nonthrowing	P
Grip			
Baseline	38.4 ± 7.9 (17.4 ± 3.6)	36.9 ± 8.3 (16.7 ± 3.8)	.54
Timepoint 1	38.9 ± 8.7* (17.6 ± 3.9)	36.1 ± 8.9 (16.4 ± 4.0)	.29
Timepoint 2	37.3 ± 8.3 (16.9 ± 3.8)	35.7 ± 7.9 (16.2 ± 3.6)	.51
Timepoint 3	35.9 ± 8.4 (16.3 ± 3.8)	36.2 ± 9.3 (16.4 ± 4.2)	.92
Jobe "full can"			
Baseline	10.0 ± 2.4 (4.5 ± 1.1)	9.3 ± 2.7 (4.2 ± 1.2)	.37
Timepoint 1	9.1 ± 1.9 (4.1 ± 0.9)	9.1 ± 1.9 (4.1 ± 0.9)	.97
Timepoint 2	9.2 ± 1.8 (4.2 ± 0.8)	9.0 ± 2.0 (4.1 ± 0.9)	.74
Timepoint 3	9.4 ± 2.3 (4.3 ± 1.0)	9.1 ± 2.2 (4.1 ± 1.0)	.61
Shoulder ER in adduction			
Baseline	10.1 ± 2.6 (4.6 ± 1.2)	10.6 ± 2.5 (4.8 ± 1.1)	.57
Timepoint 1	9.9 ± 1.9 (4.5 ± 0.9)	10.3 ± 2.2 (4.7 ± 1.0)	.54
Timepoint 2	9.3 ± 1.6 (4.2 ± 0.7)	10.3 ± 2.3 (4.7 ± 1.0)	.11
Timepoint 3	9.9 ± 1.8 (4.5 ± 0.8)	10.5 ± 2.3 (4.8 ± 1.0)	.33
Shoulder ER at 90° of abduction			
Baseline	9.9 ± 4.8 (4.5 ± 2.2)	9.6 ± 2.7 (4.4 ± 1.2)	.82
Timepoint 1	8.6 ± 2.1 (3.9 ± 1.0)	9.1 ± 2.2 (4.1 ± 1.0)	.37
Timepoint 2	9.5 ± 3.1 (4.3 ± 1.4)	9.4 ± 2.2 (4.3 ± 1.0)	.94
Timepoint 3	9.0 ± 2.3 (4.1 ± 1.0)	9.5 ± 2.5 (4.3 ± 1.1)	.55

[a]Data are reported as mean ± SD. ER, external rotation.
[b]Timepoint 1, after pitches 1-25; timepoint 2, after pitches 26-50; timepoint 3, after pitches 51-75.
*Significantly greater compared with timepoint 3 (*P* = .02).

TABLE 6
ROM Across Timepoints[a]

Timepoint[b]	ROM, deg: Throwing	Nonthrowing	P
Shoulder ER			
Baseline	114.2 ± 8.5	109.4 ± 9.5	.09
Timepoint 1	115.0 ± 8.3	110.1 ± 9.1	.07
Timepoint 2	115.9 ± 8.1	110.5 ± 9.7	.052
Timepoint 3	114.9 ± 8.0	110.6 ± 10.0	.13
Shoulder IR			
Baseline	54.7 ± 9.8	58.5 ± 8.3	.17
Timepoint 1	57.8 ± 8.1	58.6 ± 8.4	.74
Timepoint 2	57.6 ± 6.5	59.5 ± 7.6	.37
Timepoint 3	57.5 ± 7.5	59.9 ± 7.9	.31
Elbow flexion			
Baseline	156.9 ± 4.6	156.6 ± 3.6	.83
Timepoint 1	157.0 ± 3.6	157.8 ± 4.3	.52
Timepoint 2	156.9 ± 3.1	158.3 ± 3.7	.18
Timepoint 3	157.8 ± 3.4	157.8 ± 3.8	.97
Elbow extension			
Baseline	7.9 ± 3.7	7.6 ± 3.0	.82
Timepoint 1	8.4 ± 3.3	7.7 ± 3.2	.49
Timepoint 2	8.0 ± 2.7	7.9 ± 2.9	.87
Timepoint 3	7.6 ± 3.0	8.3 ± 3.6	.49

[a]Data are reported as mean ± SD. ER, external rotation; IR, internal rotation; ROM, range of motion.
[b]Timepoint 1, after pitches 1-25; timepoint 2, after pitches 26-50; timepoint 3, after pitches 51-75.

TABLE 7
Velocity for Each Set of 25 Pitches and Overall Velocity for the Combined 75 Pitches[a]

Pitching Set[b]	Velocity, mph (kph)
Baseline	-
Timepoint 1	46.5 ± 4.0 (74.8 ± 6.4)
Timepoint 2	46.2 ± 3.6 (74.4 ± 5.8)
Timepoint 3	45.7 ± 3.3 (73.5 ± 5.3)
Overall	46.1 ± 3.5 (74.2 ± 5.6)

[a]Data are reported as mean ± SD.
[b]Timepoint 1, after pitches 1-25; timepoint 2, after pitches 26-50; timepoint 3, after pitches 51-75.

TABLE 8
Accuracy for Each Set of 25 Pitches and Overall Accuracy for the Combined 75 Pitches[a]

Pitching Set[b]	Accuracy, %[c]
Baseline	-
Timepoint 1	36.6 ± 11.7
Timepoint 2	36.7 ± 13.4
Timepoint 3	34.0 ± 12.0
Overall	35.8 ± 9.7

[a]Data are reported as mean ± SD.
[b]Timepoint 1, after pitches 1-25; timepoint 2, after pitches 26-50; timepoint 3, after pitches 51-75.
[c]Accuracy was defined as percentage of pitches thrown within the strike zone.

25 pitches was significantly lower than after the third set of 25 pitches ($P \leq .02$). There was no difference in subjective fatigue between the throwing and nonthrowing arms at baseline ($P = .76$). However, after each pitching set, subjective fatigue was significantly greater in the throwing arm compared with the nonthrowing arm ($P \leq .009$).

Grip strength of the throwing arm after 75 pitches decreased significantly compared to after 25 pitches (timepoint 1 vs timepoint 3: 38.9 ± 8.7 vs 35.9 ± 8.4 pounds [17.6 ± 3.9 vs 16.3 ± 3.8 kg]; $P = .02$) (Table 5). There were no other significant differences across timepoints or between arms for grip strength. There were no statistically significant changes in the other strength measurements or ROM for all timepoints and between arms (Tables 5 and 6).

The mean overall pitching velocity for the entire cohort was 46.1 mph (74.2 kph). There were no differences in mean velocity across the 3 pitching sets (Table 7). Accuracy did not change significantly during any of the pitching sets (Table 8). The mean overall accuracy of the cohort was 35.8%.

DISCUSSION

Although this cohort of 10-year-old pitchers reported progressively increasing fatigue in the throwing arm compared with the nonthrowing arm as they pitched up to their single-game pitch count limit of 75 pitches, there was no increase in medial elbow joint line gapping, as measured by changes in medial ulnohumeral joint distance, after each pitching set. These findings differ from the findings of Hattori et al,[18] who reported increased valgus laxity immediately after repetitive pitching and again reported a significant increase in medial elbow joint space gapping after 60 pitches as compared with baseline, which further increased after 100 pitches.[19] The age difference between patients in the studies by Hattori et al[18,19] compared with our study, high school-aged versus 10-year-olds, could be a fundamental reason we did not appreciate medial joint line gapping in the current study. The current study cohort has open physes; thus, more stress could have been borne by the physis rather than the ligament. This perhaps adds to our knowledge of what is occurring with increasing pitching at the elbow at various age levels.

With the use of ultrasonography and cloud-based imaging processing to assess noninvasively relative changes in glycogen storage in the forearm flexor-pronator mass, we were able to demonstrate a decrease in glycogen storage of the flexor-pronator mass between pitching 50 and 75 pitches when compared with before pitching. This relative decrease, measured via fuel percentile based on comparison with a population of images in the utilized database, was seen only in the throwing arm. Although the actual magnitude change of this decrease cannot be determined in the present study due to the use of the standardized variable of fuel percentile, this study did demonstrate that a detectable decrease in muscle glycogen storage in the throwing forearm flexors occurs as 10-year-old players throw between 50 and 75 pitches. Subjective fatigue increased before the identification of ultrasound changes in muscle echogenicity. Grip strength in the throwing arm also significantly decreased after 75 pitches compared with grip strength after the first 25 pitches. The decrease in grip strength in the throwing arm was consistent with the increased subjective fatigue and relative decrease in muscle glycogen storage in the forearm flexor-pronator mass in the throwing extremity. Despite these findings of increased subjective and objective muscle fatigue, pitching accuracy and velocity throughout the 75 pitches did not differ significantly between the pitching sets. In addition, there were no changes in shoulder and elbow ROM and shoulder strength across timepoints and between arms.

Although limiting the amount of pitches thrown has the potential to reduce injuries to the throwing elbow, it is unclear whether the values selected for pitch count limits are appropriate based on physiologic changes in muscles of the throwing extremity and the secondary stress placed on the elbow, particularly the UCL, due to fatigue of important dynamic stabilizers of the elbow, primarily the forearm flexor-pronator mass.[32,39] The stress placed on the UCL with pitching is near or surpasses the maximum load of the UCL before failure.[11,13,27] As the flexor-pronator mass of the forearm fatigues and provides less dynamic stabilization, the UCL is less shielded and subjected to greater stress, which places the ligament at increased risk of injury. This study demonstrated that there were no significant changes in medial elbow gapping throughout the duration of pitching and between the throwing and nonthrowing elbows, despite increased subjective fatigue in the throwing arm, decreased grip strength, and ultrasound evidence of decreased glycogen storage in the throwing forearm flexors after the final set of 25 pitches compared with before the onset of pitching. Although more work is needed, it could be surmised that the more accurate pitch count for this particular age group is somewhere between 50 and 75 pitches. Although the primary outcome variable of the UCL did not increase in gapping up to the current pitch count limit of 75, the findings of reduced muscle glycogen, decreased grip strength, and increased subjective fatigue indicate that the medial elbow experiences greater stress due to decreased dynamic stabilization. It should be remembered the pitch count itself is only a portion of the total pitches and, furthermore, throws made in a game. Freehill et al[14] reported only 21% of total throws are pitches on days a youth player participates in a game in which they pitch.

To more objectively assess muscle fatigue of the forearm flexors, we utilized ultrasonography and cloud-based processing software to measure relative changes in muscle glycogen content noninvasively. The results of the current study showed that glycogen storage of the forearm flexors of the throwing arm, specifically centered on the FCR, decreases sometime between throwing 51 and 75 pitches when compared with baseline before pitching. There was a similar decline in the FCR ultrasound imaging data between each arm, although only the throwing arm data were significant between baseline and after 75 pitches ($P = .05$). The similar change in both arms, although not statistically significant except for the aforementioned difference in the throwing arm, can be interpreted to be natural due to the dynamic nature of throwing. Since both arms move during the throwing motion, it is not completely unexpected for glycogen to also be depleted in the nonthrowing arm, although not to the degree as in the throwing arm.

In addition to the change in relative glycogen content identified on ultrasound from baseline to after throwing 75 pitches in the throwing forearm along the FCR, the ultrasound imaging along the FDS and FCU identified a statistically significantly lower fuel percentile value in the nonthrowing arm compared with the throwing arm after 25 pitches ($P = .01$). However, there was no standardized imaging protocol in the cloud-based software to process these images, so the images containing the FDS and FCU muscles were processed according to the FCR protocol, and the FDS/FCU image pixel intensity were compared with the FCR image database when determining the percentile values. Therefore, these FDS/FCU measurements may have suffered from a lack of a dedicated imaging processing algorithm. Thus, this identified between-arm difference may be a result of high variability and inconsistent processing rather than a clinically relevant finding. However, we included the additional imaging of the FDS and FCU because of the importance of the muscles in proximity of the UCL and their reported activity with throwing.[1,9,17,32,38] Hence, grip strength was also utilized to evaluate changes in strength and fatigue of the forearm flexors during pitching in the current study. In fact, grip strength in the throwing arm declined after pitching 75 pitches as compared with after throwing 25 pitches. While a decrease in grip strength could be a clinical indicator of fatigue with pitching, more information is needed on whether this can serve as a surrogate for fatigue during practices and games.

Limitations

There are several limitations to this study. Although our 2 primary outcomes consisted of evaluation of medial elbow joint gapping and changes in muscle glycogen content of the forearm flexors during a pitching session, we performed the a priori power analysis based on the muscle glycogen content evaluation and not on medial elbow gapping with valgus stress. This was done because, although we expected medial elbow gapping to occur, the desire to further delineate when fatigue could arise was paramount. As a result, it is possible that the study was underpowered to demonstrate changes in medial elbow joint gapping, although this was unexpected. Importantly, although providing value in determining whether medial joint line gapping would occur in this age group, physeal injuries are likely more common in this age group and thus the findings for the primary outcome expected. The amount of valgus stress applied in the current study is lower than the 15 daN utilized in several other studies,[2,6,7] which could have led to no difference being identified with regard to medial elbow joint gapping across timepoints. The lower amount of valgus force was utilized in our study to minimize discomfort on the study participants due to their younger age as compared with the older ages of the participants, ranging from 12 to 37 years, in other studies.[2,6,7]

With regard to the ultrasound image processing, the software did not have a processing protocol and algorithm available for evaluation of the ulnar forearm flexor muscles. However, based on the 2 previous validation studies that demonstrated a high correlation between the imaging and actual change in muscle glycogen content on muscle biopsies of the rectus femoris and vastus lateralis,[20,28] we felt the muscles of the forearm flexors would be similar enough in terms of their physiology to utilize this technology for the purposes of our study. Due to the inability to establish a glycogen storage baseline for each player through multiple iterations of ultrasound imaging before the pitching evaluation, we were unable to use absolute changes in glycogen content based on the software's 0 to 100 scale, as has been used in previous studies.[20,28,35] As a result, we used percentile values to standardize the degree of pixel intensification/echogenicity of an image based on a population of scans imported previously into the image processing database as described in the Methods section. It should be noted the distribution of type 1 versus type 2 muscle fibers, as well as the physiological demands of the flexor-pronator musculature of the forearm, versus the musculature of the quadriceps, combined with the differences in muscle physiology of elite cyclists versus a 10-year-old baseball player may not be comparable. Also, a more recent review publication by Bone et al[4] that references articles chiefly concerned with problems based on the premise that the ratio of glycogen to water in muscle is constant[31,35,36]; they concluded the current evidence is at best equivocal. Thus, although this was not the primary outcome of the study, at this time the results, as they pertain to glycogen stores, should be interpreted with caution.

In addition, the partition of the total pitching into 3 sets of 25 pitches and the utilization of a prefabricated strike zone with no home plate and no batter's box does not fully simulate a true game. However, 25 pitches were chosen for each set to allow for sufficient potential changes to occur in the variables measured in the study. We felt that partitioning the pitching session into more sets consisting of a smaller number of pitches would not provide enough consistent effort and energy expenditure by the pitcher to notice any changes in the variables. An actual catcher with a home plate may have resulted in a greater percentage of strikes thrown; however, for this age group, and in the senior author's experience, this is an expected and appropriate amount of strikes. Furthermore, we were looking for deviations of accuracy and not an absolute number. Another point was that only fastballs were thrown. The FDS/FCU may be more active in other types of pitches and thus the results may not be generalizable to players who throw a significant amount of nonfastball pitches. Finally, although fatigue measurements are likely predictable with increasing throwing, the values could reflect the timing of the season or pitcher readiness for higher volume pitching.

CONCLUSION

Overall, we found that, with the recommended 75 pitch count limit in 10-year-olds, players demonstrated increased subjective fatigue and a decrease in grip strength of the throwing arm. Furthermore, we found a change in relative glycogen content of the throwing arm forearm flexor-pronator mass sometime between pitching 50 and 75 pitches compared to before the onset of pitching. This demonstrates that physiologic changes occur in the forearm flexor muscles before the pitch count limit for this age group with regard to objective muscle fatigue. However, we did not find any changes in medial elbow joint gapping when the elbow was stressed throughout the duration of the pitching session. This is likely the result of an intact and competent UCL and the fact the physis could be bearing more of the stress than the ligament in this age group. This study provides a foundation for further objective testing of physiologic changes that occur with pitching to better guide pitch count limits and subsequent improved safety of young athletes.

ORCID iD

Aaron D. Sciascia https://orcid.org/0000-0002-5518-4615

REFERENCES

1. Abe T, Thiebaud RS, Loenneke JP, Ogawa M, Mitsukawa N. Association between forearm muscle thickness and age-related loss of skeletal muscle mass, handgrip and knee extension strength and walking performance in old men and women: a pilot study. *Ultrasound Med Biol*. 2014;40(9):2069-2075.
2. Atanda AJ Jr, Averill LW, Wallace M, Niiler TA, Nazarian LN, Ciccotti MG. Factors related to increased ulnar collateral ligament thickness on stress sonography of the elbow in asymptomatic youth and adolescent baseball pitchers. *Am J Sports Med*. 2016;44(12):3179-3187.
3. Bakshi NK, Inclan PM, Kirsch JM, Bedi A, Agresta C, Freehill MT. Current workload recommendations in baseball pitchers: a systematic review. *Am J Sports Med*. 2020;48(1):229-241.
4. Bone JL, Ross ML, Tomcik KA, Jeacocke NA, McKay AKA, Burke LM. The validity of ultrasound technology in providing an indirect estimate of muscle glycogen concentrations is equivocal. *Nutrients*. 2021;13(7):2371.
5. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*. 1982;14(5):377-381.
6. Bruce JR, Hess R, Joyner P, Andrews JR. How much valgus instability can be expected with ulnar collateral ligament (UCL) injuries? A review of 273 baseball players with UCL injuries. *J Shoulder Elbow Surg*. 2014;23(10):1521-1526.
7. Ciccotti MG, Atanda AJ Jr, Nazarian LN, Dodson CC, Holmes L, Cohen SB. Stress sonography of the ulnar collateral ligament of the elbow in professional baseball pitchers: a 10-year study. *Am J Sports Med*. 2014;42(3):544-551.
8. Conte S, Requa RK, Garrick JG. Disability days in major league baseball. *Am J Sports Med*. 2001;29(4):431-436.
9. Davidson PA, Pink M, Perry J, Jobe FW. Functional anatomy of the flexor pronator muscle group in relation to the medial collateral ligament of the elbow. *Am J Sports Med*. 1995;23(2):245-250.
10. DiFiori JP, Benjamin HJ, Brenner JS, et al. Overuse injuries and burnout in youth sports: a position statement from the American Medical Society for Sports Medicine. *Br J Sports Med*. 2014;48(4):287-288.
11. Dillman CJ, Smutz P, Werner S, et al. Valgus extension overload in baseball pitching. *Med Sci Sports Exerc*. 1991;23(Suppl_4):S135.
12. Fleisig GS, Andrews JR, Cutter GR, et al. Risk of serious injury for young baseball pitchers: a 10-year prospective study. *Am J Sports Med*. 2011;39(2):253-257.
13. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. *Am J Sports Med*. 1995;23(2):233-239.
14. Freehill MT, Rose MJ, McCollum KA, Agresta C, Cain SM. Game-day pitch and throw count feasibility using a single sensor to quantify workload in youth baseball players. *Orthop J Sports Med*. 2023;11(3):23259671231151450.
15. Gregory B, Nyland J. Medial elbow injury in young throwing athletes. *Muscles Ligaments Tendons J*. 2013;3(2):91-100.
16. Gugenheim JJ Jr, Stanley RF, Woods GW, Tullos HS. Little League survey: the Houston study. *Am J Sports Med*. 1976;4(5):189-200.
17. Hamilton CD, Glousman RE, Jobe FW, Brault J, Pink M, Perry J. Dynamic stability of the elbow: electromyographic analysis of the flexor pronator group and the extensor group in pitchers with valgus instability. *J Shoulder Elbow Surg*. 1996;5(5):347-354.
18. Hattori H, Akasaka K, Otsudo T, Hall T, Amemiya K, Mori Y. The effect of repetitive baseball pitching on medial elbow joint space gapping associated with 2 elbow valgus stressors in high school baseball players. *J Shoulder Elbow Surg*. 2018;27(4):592-598.
19. Hattori H, Akasaka K, Otsudo T, Hall T, Sakaguchi K, Tachibana Y. Ulnar collateral ligament laxity after repetitive pitching: associated factors in high school baseball pitchers. *Am J Sports Med*. 2021;49(6):1626-1633.
20. Hill JC, Millan IS. Validation of musculoskeletal ultrasound to assess and quantify muscle glycogen content. A novel approach. *Phys Sportsmed*. 2014;42(3):45-52.
21. Kelly BT, Kadrmas WR, Speer KP. The manual muscle examination for rotator cuff strength. An electromyographic investigation. *Am J Sports Med*. 1996;24(5):581-588.
22. Lansdown DA, Rugg CM, Feeley BT, Pandya NK. Single sport specialization in the skeletally immature athlete: current concepts. *J Am Acad Orthop Surg*. 2020;28(17):e752-e758.
23. Larson RL, Singer KM, Bergstrom R, Thomas S. Little League survey: the Eugene study. *Am J Sports Med*. 1976;4(5):201-209.
24. Lawson BR, Comstock RD, Smith GA. Baseball-related injuries to children treated in hospital emergency departments in the United States, 1994-2006. *Pediatrics*. 2009;123(6):e1028-e1034.
25. Lyman S, Fleisig GS, Andrews JR, Osinski ED. Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. *Am J Sports Med*. 2002;30(4):463-468.
26. Lyman S, Fleisig GS, Waterbor JW, et al. Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Med Sci Sports Exerc*. 2001;33(11):1803-1810.
27. Morrey BF, An K-N. Articular and ligamentous contributions to the stability of the elbow joint. *Am J Sports Med*. 1983;11(5):315-319.
28. Nieman DC, Shanely RA, Zwetsloot KA, Meaney MP, Farris GE. Ultrasonic assessment of exercise-induced change in skeletal muscle glycogen content. *BMC Sports Sci Med Rehabil*. 2015;7:9.
29. Noble BJ, Borg GA, Jacobs I, Ceci R, Kaiser P. A category-ratio perceived exertion scale: relationship to blood and muscle lactates and heart rate. *Med Sci Sports Exerc*. 1983;15(6):523-528.
30. Olsen SJ II, Fleisig GS, Dun S, Loftice J, Andrews JR. Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. *Am J Sports Med*. 2006;34(6):905-912.
31. Ørtenblad N, Nielsen J, Gejl KD, et al. Comment on: ''Changes in skeletal muscle glycogen content in professional soccer players before and after a match by a noninvasive MuscleSound® Technology. A cross sectional pilot study Nutrients 2020, 12(4), 971.''.
32. Park MC, Ahmad CS. Dynamic contributions of the flexor-pronator mass to elbow valgus stability. *J Bone Joint Surg Am*. 2004;86(10):2268-2274.
33. Popkin CA, Bayomy AF, Ahmad CS. Early sport specialization. *J Am Acad Orthop Surg*. 2019;27(22):e995-e1000.
34. Pytiak AV, Stearns P, Bastrom TP, et al. Are the current Little League pitching guidelines adequate? A single-season prospective MRI study. *Orthop J Sports Med*. 2017;5(5):2325967117704851.
35. Routledge HE, Bradley WJ, Shepherd SO, et al. Ultrasound does not detect acute changes in glycogen in vastus lateralis of man. *Med Sci Sports Exerc*. 2019;51(11):2286-2293.
36. San-Millán I, Hill JC, Calleja-González J. Indirect assessment of skeletal muscle glycogen content in professional soccer players before and after a match through a non-invasive ultrasound technology. *Nutrients*. 2020;12(4):971.
37. Trofa DP, Obana KK, Swindell HW, et al. Increasing burden of youth baseball elbow injuries in US emergency departments. *Orthop J Sports Med*. 2019;7(5):2325967119845636.
38. Udall JH, Fitzpatrick MJ, McGarry MH, Leba T-B, Lee TQ. Effects of flexor-pronator muscle loading on valgus stability of the elbow with an intact, stretched, and resected medial ulnar collateral ligament. *J Shoulder Elbow Surg*. 2009;18(5):773-778.
39. Werner SL, Fleisig GS, Dillman CJ, Andrews JR. Biomechanics of the elbow during baseball pitching. *J Orthop Sports Phys Ther*. 1993;17(6):274-278.
40. Yang J, Mann BJ, Guettler JH, et al. Risk-prone pitching activities and injuries in youth baseball. *Am J Sports Med*. 2014;42(6):1456-1463.