JSES International 8 (2024) 577–581

Contents lists available at ScienceDirect

JSES International

journal homepage: www.jsesinternational.org

Elasticity assessment of flexor pronator muscles using shear wave elastography

Shota Hoshika, MD, PhD[a,*], Yoshiaki Itoigawa, MD, PhD[b], Norimasa Takahashi, MD, PhD[a], Hiroyuki Sugaya, MD, PhD[c], Akimoto Nimura, MD, PhD[d]

[a]Sports Medicine & Joint Center, Funabashi Orthopaedic Hospital, Funabashi, Chiba, Japan
[b]Department of Orthopaedic Surgery, Juntendo University Urayasu Hospital, Urayasu, Chiba, Japan
[c]Tokyo Sports & Orthopaedic Clinic, Toshima, Tokyo, Japan
[d]Department of Functional Joint Anatomy, Graduate School of Medical and Dental Sciences, Tokyo Medical and Dental University, Tokyo, Japan

ARTICLE INFO

Keywords:
Elasticity assessment
Flexor pronator muscles
Injury
Shear wave ultrasound elastography
Ulnar collateral ligament
Valgus stress

Level of evidence: Basic Science Study; Kinesiology

Background: The flexor pronator muscles (FPMs) have been thought as a dynamic stabilizer to protect the ulnar collateral ligament (UCL) from valgus stress during throwing motion. Thus, evaluation of the FPMs is important for preventing UCL injuries. Shear wave ultrasound elastography (SWE) is an imaging modality that quantifies tissue elasticity. The purpose of this study was to measure the tissue elasticities of healthy FPMs using SWE.

Methods: We investigated 22 healthy men (mean age, 29 ± 6 years). The elasticities of the FPMs, including the pronator teres (PT), flexor digitorum superficialis (FDS), and flexor carpi ulnaris (FCU), were measured using SWE for each arm under two conditions: at rest (unloaded) and under valgus stress (loaded). The values obtained under different loading conditions were compared between both elbows.

Results: The mean SWE values of the PT, FDS, and FCU for the dominant elbows were 22.4 ± 3.6, 22.8 ± 2.9, and 22.3 ± 3.4 kPa, respectively. The corresponding mean SWE values for the nondominant elbows were 24.2 ± 4.6, 23.1 ± 3.5, and 23.4 ± 3.5 kPa, respectively. The mean SWE values of the PT, FDS, and FCU at rest (unloaded) were 23.3 ± 4.2, 22.9 ± 3.2, and 22.9 ± 3.5 kPa, respectively. The corresponding mean SWE values under valgus stress (loaded) were 35.0 ± 6.2, 34.7 ± 5.3, and 31.9 ± 4.8 kPa, respectively.

Conclusion: This noninvasive evaluation of the stiffness of the FPMs may provide clinically relevant data for the prevention of UCL injuries.

In baseball pitchers, the increasing frequencies of ulnar collateral ligament (UCL) injuries in the elbow and the required surgeries are of utmost concern.[6,26] The anterior bundle of the UCL is the primary static stabilizer against valgus stress.[4,22] The flexor pronator muscles (FPMs), including the pronator teres (PT), flexor digitorum superficialis (FDS), and flexor carpi ulnaris (FCU), are secondary dynamic stabilizers.[1,5,8,11,12,14,24,25,30,31] The anterior bundle of the UCL has been recently described as a part of the tendinous complex comprising FPMs.[17] Stiffness and tenderness of FPMs are the most frequently observed clinical signs of UCL injuries in baseball pitchers. Although evaluating the stiffness of FPMs is necessary to determine the pathogenic mechanisms underlying the elbow symptoms, no reliable diagnostic tools are available to do this. This diagnostic tool may prevent UCL ruptures or lesions by determining the degree of stiffness.

Shear wave elastography (SWE) has been used as a quantitative ultrasound (US) technique to assess muscle stiffness by evaluating shear wave propagation speed.[10,20,32] Although SWE has been frequently used for quantitative evaluations of the UCL,[13,21] no studies have used this technique to assess the mechanical stiffness of FPMs.

This preliminary study aimed to evaluate a method for measuring the stiffness of healthy FPMs (including PT, FDS, and FCU) using SWE. We also compared the stiffness of FPMs under two separate conditions: at rest (unloaded) and under valgus stress (loaded). We hypothesized that the stiffness of individual FPMs can be quantified by SWE and may differ between the loaded and unloaded conditions.

This study was approved by the institutional review board of Funabashi Orthopaedic Hospital at 19th September 2018 (No. 2018033).

*Corresponding author: Shota Hoshika, MD, PhD, Sports Medicine & Joint Center, Funabashi Orthopaedic Hospital, 1-833 Hasama, Funabashi, Chiba 274-0822, Japan.
E-mail address: shoshika@fff.or.jp (S. Hoshika).

https://doi.org/10.1016/j.jseint.2024.01.002

Figure 1 Positioning for the ultrasound examination. The participant was laid on the bed with the shoulder, elbow, and forearm at 90° abduction, 90° flexion, and a neutral position, respectively. Ultrasonography images were acquired from the medial elbow.

Materials and methods

Design

This study used a repeated-measures examination to evaluate changes in SWE under two separate elbow-loading conditions. The dependent variable was SWE, and the independent variables were the loading conditions (unloaded and loaded). The dominant and nondominant elbows of all participants were subjected to both loading conditions. PT, FDS, and FCU were also assessed separately under these conditions.

Participants

Twenty two healthy individuals aged 22-44 (mean, 29 ± 6) years were recruited from our institute between December 2018 and November 2019. Only men were registered in order to simulate the baseline characteristics of adult male baseball players. The exclusion criteria were as follows: (1) present pain or injury of the upper limbs, (2) previous traumatic UCL injury or elbow dislocation, (3) previous surgery of the upper limbs, and (4) prior involvement in overhead sports. Written informed consent was obtained from all participants, and the study was approved by the appropriate institutional review board.

Imaging technique

All US scans were obtained by a well-trained orthopedic surgeon using an Aixplorer (Supersonic Imagine, Aix-en-Provence, France) scanner with a 10-MHz linear transducer; these scans were used to evaluate the material properties of the muscle (along the muscle fiber direction). This device was equipped with SWE technology and enabled the quantification of tissue elasticity without probe compression. Each participant was laid on the bed with the shoulder, elbow, and forearm at 90° abduction, 90° flexion, and a neutral position, respectively (Fig. 1).[29] All angles were measured using a goniometer. SWE evaluation in this study allowed two-dimensional SWE, which in turn allowed the measurement of tissue stiffness with a conventional US transducer. SWE values were calculated in a region of interest (ROI) according to a previous report.[9] ROIs were identified using the tendinous septum (TS) as a landmark. SWE values ranged from 0 to 800 kPa. Each SWE value was measured three times, and the mean value was used.

SWE for individual FPMs across the two conditions

The transducer was placed on the medial elbow to visualize FPMs. First, a short-axis scan was used to identify TS between PT and FDS, as well as TS between FDS and FCU, in accordance with previous studies (Fig. 2, *a*).[7,17] Second, these TSs were used as landmarks for differentiating between PT, FDS, and FCU. Third, after identifying these muscles in the short-axis views, the transducer was turned 90° to observe the muscles along their long-axis (Fig. 2, *b-d*). It has been reported that to quantify muscle stiffness by SWE, the US transducer must be oriented parallel to the muscle fibers.[10] Therefore, each muscle was identified along its long-axis during SWE at the level of the sublime tubercle of the ulna.

SWE measurements of the dominant and nondominant elbows were performed under the following conditions: forearm resting on a handstand (unloaded; Fig. 3, *a*) and forearm held without any support (loaded; Fig. 3, *b*).[31] An elbow was randomly selected for SWE measurements of FPMs, which were recorded under the unloaded and loaded conditions. Thereafter, SWE measurements for the opposite elbow were similarly obtained. Changes in SWE values, which reflected the differences in SWE findings between the two conditions, were used for subsequent analyses. None of the participants experienced medial elbow pain during the examinations.

Statistical analysis

A paired *t*-test was used to compare SWE values of PT, FDS, and FCU between the dominant and nondominant elbows and between the two conditions. A two-sided P value of $< .05$ was considered statistically significant. Power analysis for the detection of differences between the different loading conditions in each elbow was conducted using an α-value of 0.05, an effect size of 0.4 (determined according to the results of a preliminary study), and a power of 0.95. The power analysis suggested that 44 elbows were required to evaluate the two conditions.

Results

In all participants, the muscle fibers of FPMs were identified on B-mode US images (Fig. 2), and muscle stiffness was measured with SWE (Fig. 4). The mean SWE values of PT, FDS, and FCU for the dominant elbows were 22.4 ± 3.6, 22.8 ± 2.9, and 22.3 ± 3.4 kPa, respectively (Table I). The corresponding mean SWE values for the nondominant elbows were 24.2 ± 4.6, 23.1 ± 3.5, and 23.4 ± 3.5 kPa, respectively (Table I). There were no significant differences in SWE values for the muscles between the dominant and nondominant elbows (Table I). The mean SWE values of PT, FDS, and FCU under unloaded conditions were 23.3 ± 4.2, 22.9 ± 3.2, and 22.9 ± 3.5 kPa, respectively (Table II). The corresponding mean SWE values under loaded conditions were 35.0 ± 6.2, 34.7 ± 5.3, and 31.9 ± 4.8 kPa, respectively (Table II). The mean SWE values under the loaded conditions were significantly greater than the SWE values under the unloaded conditions (Table II).

Discussion

In this study, PT, FDS, and FCU were identified in the short-axis views of the US by using TS as a landmark. The muscle fibers of all FPMs were then individually identified along their long axis. SWE was used to quantify the stiffness of PT, FDS, and FCU. No significant differences were observed in SWE values between both elbows. SWE values of FPMs under the loaded conditions were greater than those under the unloaded conditions, thereby validating our hypothesis.

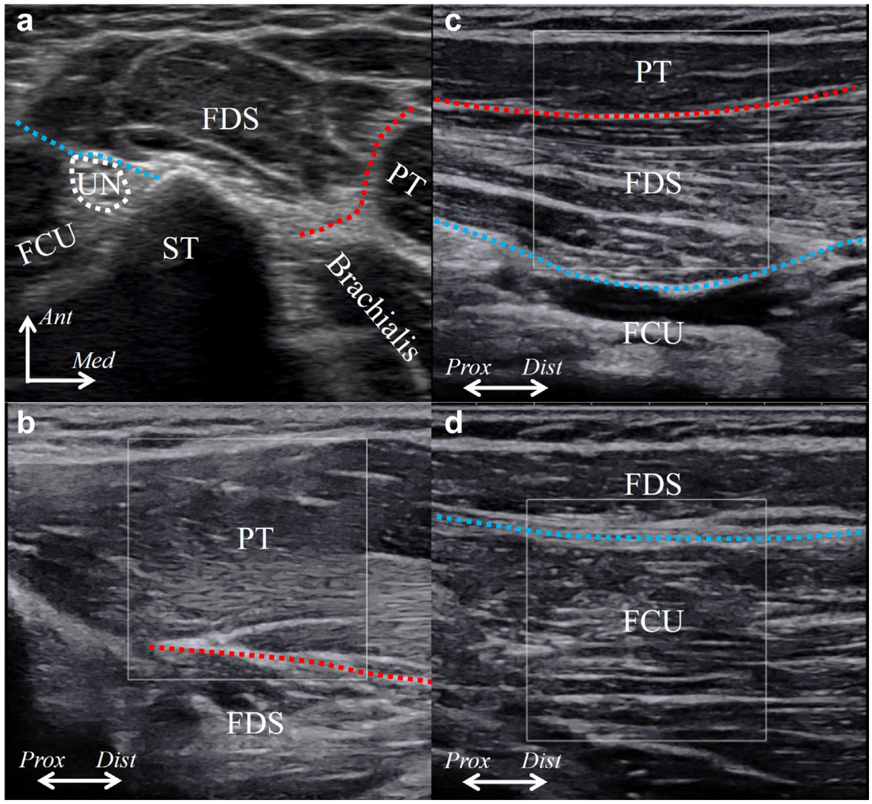

Figure 2 Ultrasound images of the flexor pronator muscles. (**a**) Short-axis image at the level of the sublime tubercle in the ulna. Two tendinous septa, one between PT and FDS (—), and one between FDS and FCU (—), were identified. (**b**) Long-axis image of PT of the medial elbow. (**c**) Long-axis image of FDS of the medial elbow. (**d**) Long-axis image of FCU of the medial elbow. *Ant*, anterior; *Dist*, distal; *FCU*, flexor carpi ulnaris; *FDS*, flexor digitorum superficialis; *Med*, medial; *Prox*, proximal; *PT*, pronator teres; *UN*, ulnar nerve; *ST*, sublime tubercle.

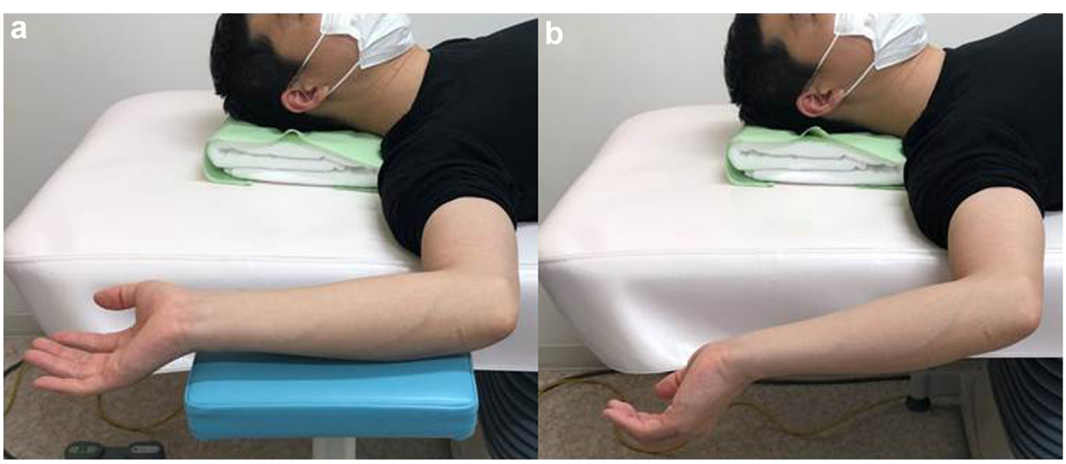

Figure 3 Ultrasound examination under different loading conditions. (**a**) Forearm on the handstand (unloaded). (**b**) Forearm without support (loaded).

We demonstrated a method for the assessment of the elasticity of individual FPMs. To ensure sufficient shear wave propagation, the US transducer must be oriented parallel to the muscle fibers to quantitatively assess muscle stiffness during SWE.[10] Previously, it was difficult to identify FPMs alone in the long-axis scans.[7] A recent anatomical study revealed two TSs, one between PT and FDS and one between FDS and FCU.[17] Based on these anatomical findings, it was possible to use the two TSs as landmarks for identifying PT, FDS, and FCU in both the long-axis and short-axis views.

Quantitative assessment of the muscle elasticity of FPMs is necessary for managing players with a UCL injury, based on the anatomical finding that the UCL could be a part of the tendinous complex comprising FPMs. US strain elastography allows a semi-quantitative assessment of muscle elasticity through strain ratios.[2] SWE has been reported to be a more accurate diagnostic tool than conventional strain elastography due to its improved reproducibility and quantification of muscle elasticity.[23] Previous studies have reported the use of SWE in assessing the tissue elasticity of the UCL of the elbow[13,21]; however, this modality has rarely been

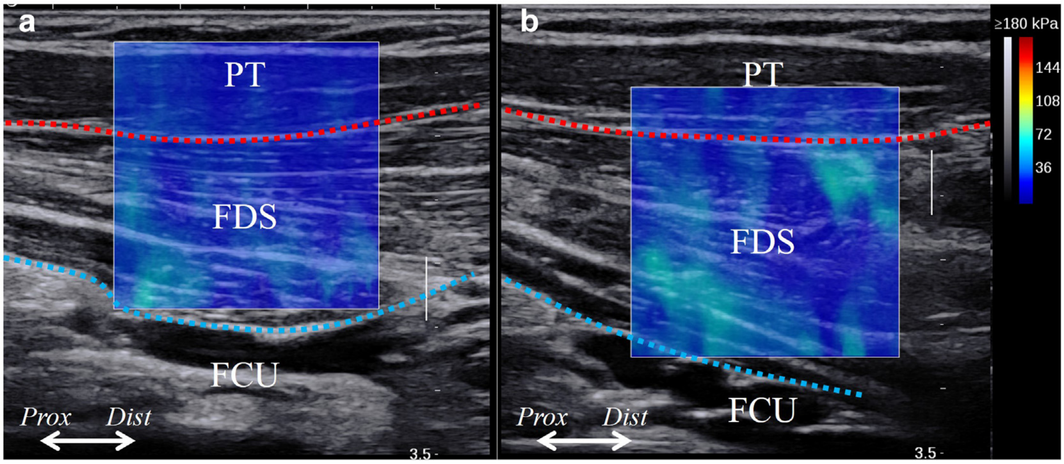

Figure 4 Shear wave elastography evaluation of the flexor pronator muscles. PT, FDS, and FCU were identified by two tendinous septa, one between PT and FDS (*red dotted line*) and the other between FDS and FCU (*blue dotted line*). The colored region represents the shear elasticity map with the scale to the Right of the figure (blue, soft; green to yellow, medium; red, hard). (**a**) Long-axis image of the flexor pronator muscle under the unloaded condition. (**b**) Long-axis image of the flexor pronator muscle under the loaded condition. *Dist*, distal; *FCU*, flexor carpi ulnaris; *FDS*, flexor digitorum superficialis; *PT*, pronator teres; *Prox*, proximal.

Table I
Shear wave elastography values of elbows on the dominant and nondominant sides.

	Dominant elbow	Nondominant elbow	*P* value
SWE value [mean ± SD]			
PT	22.4 ± 3.6	24.2 ± 4.6	.07
FDS	22.8 ± 2.9	23.1 ± 3.5	.58
FCU	22.3 ± 3.4	23.4 ± 3.5	.08

SWE, Shear wave elastography; *PT*, pronator teres; *FDS*, flexor digitorum superficialis; *FCU*, flexor carpi ulnaris; *SD*, standard deviation.
Values are expressed as kPa (mean ± standard deviation).

Table II
Shear wave elastography values in the unloaded and loaded conditions.

	Rest	Valgus stress	*P* value
SWE value [mean ± SD]			
PT	23.3 ± 4.2	35.0 ± 6.2	<.001
FDS	22.9 ± 3.2	34.7 ± 5.3	<.001
FCU	22.9 ± 3.5	31.9 ± 4.8	<.001

SWE, Shear wave elastography; *PT*, pronator teres; *FDS*, flexor digitorum superficialis; *FCU*, flexor carpi ulnaris; *SD*, standard deviation.
Values are expressed as kPa (mean ± standard deviation).

applied to the assessment of FPMs. Therefore, our new method for evaluating the muscle stiffness of FPMs using SWE might contribute to the assessment of baseball players with a UCL injury.

It is unclear how pitching motion affects the stiffness of each FPM because FPMs work differently during the throwing motion. Muscle stiffness has been reported to result from both active tension produced during muscle contraction and passive tension due to muscle extension in the longitudinal direction.[16,18] Some studies have reported that muscle elasticity increases during contraction.[20,27] In addition, a previous elastography study reported that a repetitive throwing motion could lead to muscular stiffness.[19] These previous studies indicate that the stiffness of FPMs may be due to their active contraction and passive extension during the throwing motion. In the current study, US examination is a dynamic method which allows measuring the muscle stiffness under unloaded and loaded conditions during the same examination. In addition, SWE values for FPMs were greater under loaded conditions than under unloaded conditions. Our findings may inform the development of future studies on healthy and injured baseball players.

Some implications could be deduced from the results of this study. First, we hypothesize that the use of SWE in baseball players may facilitate prevention of medial elbow injury. Some studies have reported that UCL injuries correlate with increased elasticity in FPMs.[28] In the current study, no significant differences were observed in SWE values of the individual FPMs between the dominant and nondominant elbows. And this technique may be used easily for other examiners with the two TSs as landmarks for identifying each FPM. Therefore, this technique could be used as screening method for symptomatic baseball players to identify pathological stiffness by comparing both elbows.

Second, we hypothesize that the use of SWE in baseball players may facilitate management medial elbow. It has been reported that repeated pitching caused the stiffness of the FPMs.[15] And a delay in the isometric force response time in stiff muscles results in a decrease in dynamic stability against valgus stress.[3,19] Therefore, this quantitative tool for assessing the degree of stiffness before and after pitching may be useful for management of medial elbow.

This study had several limitations. First, the SWE value was measured by one examiner, and the reliability was not assessed. Second, only healthy participants were included in the study. Third, the locations of the ROIs were not standardized. Forth, we used gravity alone to load the elbow, not using other equipment such as weighted ball. Further research on how force variation affects the load on the FPMs may be required. Lastly, not all regions of the ligaments and muscles were evaluated; therefore, the results may not appropriately represent an exact clinical scenario. We believe that this study provides important quantitative data on the stiffness of FPMs with respect to UCL injuries in baseball players.

Conclusion

This study evaluated a method for measuring the stiffness of healthy FPMs (including PT, FDS, and FCU) using SWE. We hypothesized that the stiffness of individual FPMs can be quantified by SWE and would differ between loaded and unloaded conditions. Our results demonstrated that the stiffness of each FPM could be quantified using SWE. No significant differences were observed in SWE values between both elbows. In addition, SWE values in FPMs under the loaded conditions were greater than those under the unloaded conditions. This study indicated that noninvasive evaluation of the stiffness of FPMs using SWE might provide clinically relevant information for preventing UCL injuries in baseball players.

Acknowledgment

The authors are grateful for all volunteers who participated in this study.

Disclaimers:

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.
Conflicts of interest: The authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.
Patient consent: Written informed consent was obtained from all participants.

References

1. An KN, Hui FC, Morrey BF, Linscheid RL, Chao EY. Muscles across the elbow joint: a biomechanical analysis. J Biomech 1981;14:659-69.
2. Arda K, Ciledag N, Aktas E, Aribas BK, Köse K. Quantitative assessment of normal soft-tissue elasticity using shear-wave ultrasound elastography. AJR Am J Roentgenol 2011;197:532-6. https://doi.org/10.2214/AJR.10.5449.
3. Blackburn JT, Bell DR, Norcross MF, Hudson JD, Engstrom LA. Comparison of hamstring neuromechanical properties between healthy males and females and the influence of musculotendinous stiffness. J Electromyogr Kinesiol 2009;19:e362-9. https://doi.org/10.1016/j.jelekin.2008.08.005.
4. Ciccotti MC, Hammoud S, Dodson CC, Cohen SB, Nazarian LN, Ciccotti MG. Stress ultrasound evaluation of medial elbow instability in a cadaveric model. Am J Sports Med 2014;42:2463-9. https://doi.org/10.1177/0363546514542805.
5. 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;23:245-50.
6. DeFroda SF, Goodman AD, Gil JA, Owens BD. Epidemiology of elbow ulnar collateral ligament injuries among baseball players: National Collegiate Athletic Association injury surveillance program, 2009-2010 through 2013-2014. Am J Sports Med 2018;46:2142-7. https://doi.org/10.1177/0363546518773314.
7. De Maeseneer M, Brigido MK, Antic M, Lenchik L, Milants A, Vereecke E, et al. Ultrasound of the elbow with emphasis on detailed assessment of ligaments, tendons, and nerves. Eur J Radiol 2015;84:671-81. https://doi.org/10.1016/j.ejrad.2014.12.007.
8. Digiovine NM, Jobe FW, Pink M, Perry J. An electromyographic analysis of the upper extremity in pitching. J Shoulder Elbow Surg 1992;1:15-25.
9. Eby SF, Cloud BA, Brandenburg JE, Giambini H, Song P, Chen S, et al. Shear wave elastography of passive skeletal muscle stiffness: influences of sex and age throughout adulthood. Clin Biomech (Bristol, Avon) 2015;30:22-7. https://doi.org/10.1016/j.clinbiomech.2014.11.011.
10. Eby SF, Song P, Chen S, Chen Q, Greenleaf JF, An KN. Validation of shear wave elastography in skeletal muscle. J Biomech 2013;46:2381-7. https://doi.org/10.1016/j.jbiomech.2013.07.033.
11. Frangiamore SJ, Moatshe G, Kruckeberg BM, Civitarese DM, Muckenhirn KJ, Chahla J, et al. Qualitative and quantitative analyses of the dynamic and static stabilizers of the medial elbow: an anatomic study. Am J Sports Med 2018;46:687-94. https://doi.org/10.1177/0363546517743749.
12. Glousman RE, Barron J, Jobe FW, Pink M. An electromyographic analysis of the elbow in normal and injured pitchers with medial collateral ligament insufficiency. Am J Sports Med 1992;20:311-7.
13. Gupta N, Labis JS, Harris J, Trakhtenbroit MA, Peterson LE, Jack RA 2nd, et al. Shear-wave elastography of the ulnar collateral ligament of the elbow in healthy volunteers: a pilot study. Skeletal Radiol 2019;48:1241-9. https://doi.org/10.1007/s00256-019-3162-2.
14. 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;5:347-54.
15. Hattori H, Akasaka K, Otsudo T, Hall T, Sakaguchi K, Tachibana Y. Comparison of elbow valgus laxity and medial elbow stabilizer parameters during repetitive pitching between high school baseball players with and without a history of medial elbow injury. J Shoulder Elbow Surg 2022;31:2602-10. https://doi.org/10.1016/j.jse.2022.07.032.
16. Hill AV. The heat of shortening and the dynamic constants of muscle. Proc R Soc Lond B Biol Sci 1938;126:136-95.
17. Hoshika S, Nimura A, Yamaguchi R, Nasu H, Yamaguchi K, Sugaya H, et al. Medial elbow anatomy: a paradigm shift for UCL injury prevention and management. Clin Anat 2019;32:379-89. https://doi.org/10.1002/ca.23322.
18. Huxley AF. Muscle structure and theories of contraction. Prog Biophys Biophys Chem 1957;7:255-318.
19. Inami T, Tsujimura T, Shimizu T, Watanabe T, Lau WY, Nosaka K. Relationship between isometric contraction intensity and muscle hardness assessed by ultrasound strain elastography. Eur J Appl Physiol 2017;117:843-52. https://doi.org/10.1007/s00421-016-3528-2.
20. Itoigawa Y, Sperling JW, Steinmann SP, Chen Q, Song P, Chen S, et al. Feasibility assessment of shear wave elastography to rotator cuff muscle. Clin Anat 2015;28:213-8. https://doi.org/10.1002/ca.22498.
21. Lin C, Sadeghi S, Bader DA, Cortes DH. Ultrasound shear wave elastography of the elbow ulnar collateral ligament: reliability test and a preliminary case study in a baseball pitcher. J Eng Sci Med Diagn Ther 2018;1, 011004. https://doi.org/10.1115/1.4038259.
22. Morrey BF, An KN. Functional anatomy of the ligaments of the elbow. Clin Orthop Relat Res 1985:84-90.
23. Ooi CC, Malliaras P, Schneider ME, Connell DA. "Soft, hard, or just right?" Applications and limitations of axial-strain sonoelastography and shear-wave elastography in the assessment of tendon injuries. Skeletal Radiol 2014;43:1-12. https://doi.org/10.1007/s00256-013-1695-3.
24. Park MC, Ahmad CS. Dynamic contributions of the flexor-pronator mass to elbow valgus stability. J Bone Joint Surg Am 2004;86:2268-74. https://doi.org/10.2106/00004623-200410000-00020.
25. Pexa BS, Ryan ED, Myers JB. Medial elbow joint space increases with valgus stress and decreases when cued to perform a maximal grip contraction. Am J Sports Med 2018;46:1114-9. https://doi.org/10.1177/0363546518755149.
26. Rebolledo BJ, Dugas JR, Bedi A, Ciccotti MG, Altchek DW, Dines JS. Avoiding Tommy John surgery: what are the alternatives? Am J Sports Med 2017;45:3143-8. https://doi.org/10.1177/0363546517692548.
27. Saito A, Minagawa H, Watanabe H, Kawasaki T, Okada K. Elasticity of the pronator teres muscle in youth baseball players with elbow injuries: evaluation using ultrasound strain elastography. J Shoulder Elbow Surg 2018;27:1642-9. https://doi.org/10.1016/j.jse.2018.05.021.
28. Saito A, Okada K, Shibata K, Sato H, Namiki Y, Terui Y, et al. Elasticity of the forearm flexor-pronator muscles as a risk factor for medial elbow injuries in young baseball players: a prospective cohort study of 314 players. Am J Sports Med 2023;51:3409-15. https://doi.org/10.1177/03635465231202028.
29. Sasaki J, Takahara M, Ogino T, Kashiwa H, Ishigaki D, Kanauchi Y. Ultrasonographic assessment of the ulnar collateral ligament and medial elbow laxity in college baseball players. J Bone Joint Surg Am 2002;84:525-31. https://doi.org/10.2106/00004623-200204000-00003.
30. Sisto DJ, Jobe FW, Moynes DR, Antonelli DJ. An electromyographic analysis of the elbow in pitching. Am J Sports Med 1987;15:260-3.
31. Udall JH, Fitzpatrick MJ, McGarry MH, Leba TB, 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;18:773-8. https://doi.org/10.1016/j.jse.2009.03.008.
32. Wada T, Itoigawa Y, Yoshida K, Kawasaki T, Maruyama Y, Kaneko K. Increased stiffness of rotator cuff tendons in frozen shoulder on shear wave elastography. J Ultrasound Med 2020;39:89-97. https://doi.org/10.1002/jum.15078.