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Title: Chronic Adaptations of the Ulnar Nerve in Professional Baseball Pitchers

Running Title: Ulnar Nerve Adaptations in Pitchers

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Abstract

Context: Screening programs to identify negative ulnar nerve adaptations in throwing athletes can help minimize injury risk and individualize treatment programs prior to the onset of symptoms. However, it is currently unclear how the ulnar nerve structurally adapts chronically in professional baseball pitchers.

Objective: To compare ulnar nerve ultrasound structural characteristics between the throwing (dominant) and non-throwing control (non-dominant) elbows in professional pitchers, with a secondary purpose of comparing ultrasound structural characteristics between subluxating and non-subluxating ulnar nerves.

Design: Cross-sectional study.

Setting: The beginning of the 2022 Minor League Baseball spring training of a single professional baseball organization.

Participants: All asymptomatic professional baseball pitchers from a single organization.

Main Outcome Measures: Bilateral elbow ultrasound examinations by a musculoskeletal radiologist for subsequent image quantification of ulnar nerve properties (echogenicity, area, circularity), as well as to identify ulnar nerve subluxation.

Results: Overall, 67 male professional baseball pitchers were enrolled. No significant bilateral differences in ulnar nerve cross-sectional area (dominant: 0.2 cm^2 vs. non-dominant: 0.2 cm^2, $p=0.4$), echogenicity (137 pixel intensity vs. 128 pixel intensity, $p=0.07$), or circularity (0.67 vs. 0.69, $p=0.4$) were observed. Ulnar nerve echogenicity was significantly lower in subluxating dominant ulnar nerves compared to non-subluxating dominant ulnar nerves (127 pixel intensity vs. 143 pixel intensity, p=0.006), while no significant differences in ulnar nerve area (0.2 mm^2 vs. 0.2 mm^2, p=0.1) or circularity (0.68 vs. 0.66, p=0.4) were observed between groups.

Conclusion: The ulnar nerve of the throwing elbow had similar cross-sectional area, echogenicity, and circularity compared to the non-dominant ulnar nerve. Nerve echogenicity was significantly decreased in subluxating ulnar nerves, however further research is necessary to determine why this difference exists and the potential direction of causality.

Keywords: ulnar nerve, ultrasound, adaptation, baseball, pitcher, elbow

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Key Points:

1. Ulnar nerve cross-sectional area, echogenicity, and circularity do not undergo chronic adaptations due to the stress of throwing in asymptomatic pitchers.
2. Subluxating ulnar nerves had a decreased echogenicity compared to non-subluxating ulnar nerve, however further research is needed to determine the clinical relevance of this.

Introduction

There is substantial biomechanical stress to the upper extremity during the throwing motion, especially during the late cocking and early acceleration phases of pitching.[1–6] Because of this, the upper extremity of baseball pitchers is vulnerable to injury. In an analysis of nearly fifty thousand Major and Minor League Baseball injuries, it was found that 4.5% affected the elbow.[7] Extensive healing and rehabilitation times are often needed for these athletes to return to play after elbow injuries, making these injuries a significant burden in the baseball population.[6,8]

Studies indicate that prolonged, repetitive pitching can irritate and compress the ulnar nerve.[9,10] Ulnar neuritis is responsible for 13% of all reported elbow injuries in professional baseball, with players missing on average four months of play and 14% of players requiring surgical intervention.[7] Due to the proximity of the ulnar nerve to key anatomical structures in the elbow, ulnar neuritis often presents with concomitant injuries such as ulnar collateral ligament (UCL) tears, flexor-pronator strains, and olecranon fractures.[11] However, surgical outcomes tend to be inferior for athletes who undergo UCL reconstruction with pre-operative ulnar nerve symptoms compared to those who undergo similar procedures without preoperative neural involvement. For example, De Giacomo et al.[12] found that only 82% of players diagnosed with ulnar neuritis prior to UCL reconstruction (UCLR) returned to play while 92% of players without pre-operative ulnar neuritis returned to play. Furthermore, Lynch et al.[13] found that 84% of patients who undergo UCLR with concomitant ulnar nerve transposition (UNT) are able to return to sport while 93% of patients who undergo isolated UCLR are able to return to sport, though this was not a statistically significant difference in this study. Ulnar neuritis is also a well-documented postoperative complication of UCLR, with a reported incidence of 5-16% following reconstruction.[14,15] Furthermore, isolated ulnar nerve decompression/transposition in professional baseball players only provides a return to sport rate of 62%.[16] As such, it would be beneficial to determine which players are at risk for ulnar nerve issues and implement strategies to mitigate this pathology.

Ultrasound is a convenient, noninvasive diagnostic tool that provides the advantage of viewing structural adaptations to the ulnar nerve prior to the potential onset of symptoms.[17] Ultrasound has identified chronic adaptations in anterior translation distance (ATD) of the ulnar nerve, with high school pitchers having a greater bilateral difference in ATD compared to position players and non-throwing controls.[18] Ultrasound has also shown that ulnar nerve cross-sectional area increases throughout the season in high school baseball pitchers and is associated with pitching workload.[19]

While adaptations to the ulnar nerve have been evaluated in adolescent baseball players, ulnar nerve adaptations have not been evaluated in professional baseball pitchers, a population with high pitching velocities and workload. Using ultrasound to visualize ulnar nerve adaptations may help minimize injury risk and optimize treatment programs by early identification of any potentially deleterious ulnar nerve adaptations prior to the onset of symptoms. Therefore, the primary objective of this study was to compare ulnar nerve ultrasound characteristics between the throwing (dominant) and non-throwing control (non-dominant) elbows in professional pitchers. A secondary purpose was to compare ultrasound characteristics between subluxating and non-subluxating ulnar nerves. The authors hypothesized that ulnar nerve area and echogenicity (i.e., brightness) would be increased in the throwing elbow, and that subluxating ulnar nerves would also have increased echogenicity.

Methods

Participants

This study was approved by our Institutional Review Board (**). All Minor League Baseball pitchers from a single professional baseball organization underwent medical evaluation and study enrollment at the beginning of the 2022 Minor League Baseball spring training prior to the beginning of competitive games. Pitchers were only included if they: were at least 18 years of age, were healthy and eligible for participation in team activities, did not have a history of UCL surgery or ulnar nerve transposition, and had not undergone upper extremity surgery within the past year. Pitchers with a prior ulnar nerve transposition, prior UCL reconstruction or repair, history of carpal tunnel or cubital tunnel releases, history of thoracic outlet syndrome (TOS), or history of first rib resection were excluded. Demographics regarding player age, BMI, hand dominance, and years of professional baseball experience were collected.

Data Collection

Pitchers were enrolled in this study during standard-of-care preseason medical screening. Pitchers who agreed to participate underwent bilateral ultrasound imaging of the elbow with a 15 MHz multifrequency linear array transducer (HFL 50X, Edge II, FUJIFILM Sonosite Inc., Bothell, WA) by a musculoskeletal radiologist (**) with over 20 years of clinical and ultrasound experience with the baseball population. The bilateral ulnar nerves were specifically scanned for study purposes after standard-of-care imaging. The non-dominant elbow was used as the control comparison to the dominant elbow, which has been shown to be a reliable reference in structures <2 mm.[20] Previous research has found that nerve size did not differ bilaterally, however there were positive correlations between BMI and nerve size as well as between age and nerve size,[21] suggesting that the bilateral comparison performed in this study would control for age and BMI and thus minimize these effects on ulnar nerve size.

The ulnar nerve was identified with ultrasound by placing the probe at the cubital tunnel, between the acoustic landmarks of the medial epicondyle and olecranon and identifying the typical fascicular pattern of the ulnar nerve. Images were obtained both at rest and with full active elbow flexion. The nerve was determined to be subluxated via ultrasound if it left the groove to lie either superficial or anterior to the medial epicondyle during active elbow flexion (Figures 1 and 2). Bilateral ultrasound images of the ulnar nerve were captured on the machine hard drive and saved for later processing.

Standard-of-care evaluation also included Beighton score assessments, a reliable evaluation of joint hypermobility.[22] Beighton scores ranged from 0-5 in the current study because evaluations were limited to just the throwing arm.

Image Analysis

The ulnar nerve ultrasound images were analyzed according to the procedures outlined by Chen et al.[23] Ultrasound images were imported to Image J software (National Institutes of Health, Bethesda, MD) in order to quantify ulnar nerve cross-sectional area, echogenicity (i.e., brightness), and circularity, with evaluation of nerve area and echogenicity shown to have excellent interrater and intrarater reliability.[24] Echogenicity is measured in pixel intensity and ranges from 0 (pure black) to 255 (pure white), and circularity ranges from 0 (completely flat) to 1 (a perfect circle). Echogenicity of the ulnar nerve has been shown to have great interrater

(R=0.89) and intrarater (intraclass coefficient 0.99) reliability.[25] All image analyses were performed by one investigator (**) who was blinded to arm dominance and subluxation findings. The ulnar nerve was identified near the medial epicondyle as a hypoechoic area with a hyperechoic border consistently surrounding the nerve (i.e., epineurium). The outer border of the epineurium was traced so that image analysis included both the ulnar nerve and its respective epineurium.

Statistical Analysis

A 2 (arm) x 2 (group) ANOVA with repeated measures for arm was performed. Cohen's D effect size was calculated when comparing ultrasound measures between groups. Statistical significance was set at 0.05. All statistical analyses were done using SPSS Version 25 (IBM Corp).

Results

Overall, 67 male professional baseball pitchers (age: 22 ± 2 years; BMI 27 ± 3; 67% right-hand dominant; professional experience: 2 ± 2 years, Beighton score 2.3 ± 1.3) were enrolled. No significant bilateral differences in ulnar nerve cross-sectional area (dominant: 0.2 cm^2 vs. non-dominant: 0.2 cm^2, p=0.4, effect size=0.16), echogenicity (137 pixel intensity vs. 128 pixel intensity, p=0.07, effect size=0.29), or circularity (0.67 vs. 0.69, p=0.4, effect size=0.17) were observed (Table 1).

There were 44 elbows with ulnar nerve subluxation (age 22±2 years, BMI 26±3, 3.5±3.3 years professional experience, 52% [23/44] dominant elbow, Beighton score 2.3±1.4) and 90 ulnar nerves without subluxation (age 23±2 years, BMI 27±3, 3.3±1.8 years professional experience, 49% [44/90] dominant elbow, Beighton score 2.3±1.3). Ulnar nerve echogenicity was significantly lower in subluxating ulnar nerves compared to non-subluxating ulnar nerves (127 pixel intensity vs. 143 pixel intensity, p=0.006), while no significant differences in ulnar nerve area (0.2 mm^2 vs. 0.2 mm^2, p=0.1) or circularity (0.68 vs. 0.66, p=0.4) were observed between groups (Table 2).

There was no significant interaction effect between arm and ulnar nerve subluxation for cross-sectional area (p=0.9), ulnar nerve echogenicity (p=0.8), or ulnar nerve circularity (p=0.9) (Table 3).

Discussion

The hypotheses of this study were rejected, as the measured ulnar nerve characteristics (cross-sectional area, echogenicity, circularity) did not differ bilaterally, and subluxating ulnar nerves had significantly decreased echogenicity compared to non-subluxating ulnar nerves.

Increased echogenicity has been associated with nerve friction due to increased collagen deposition.[26] Rivlin et al.[26] found that injury of the sciatic nerve in rabbits triggered responses in Schwann cells and fibroblastic cells, with both cells contributing to collagen deposition during fibrosis. It is possible that since the throwing motion likely involves larger friction between the ulnar nerve and the olecranon, it is reasonable to assume a greater overall collagen composition in the throwing arm, which may explain why the current study found that dominant ulnar nerve echogenicity trended towards having a significantly higher echogenicity (137 pixel intensity vs. 128 pixel intensity, p=0.07) than the non-dominant ulnar nerve.

Several other studies have evaluated the ulnar nerve using ultrasound in baseball players. For example, Tai et al.[18] used high-resolution ultrasound to examine the ulnar nerve in adolescent baseball players, finding that pitchers displayed a greater anterior translation distance (ATD) of the ulnar nerve in the dominant elbow. Additionally, adolescent pitchers were noted to have a statistically significant difference in ATD between their dominant and non-dominant ulnar nerves (+1.6 mm) compared to field players and controls (-0.3 mm and -0.7 mm respectively), reflecting increased chronic adaptations in the high school pitchers' nerves.[18] However, it is unclear whether increased ATD is a positive or negative adaptation to repetitive throwing.

Ultrasound has also been used to evaluate changes in ulnar nerve characteristics from pre-season to post-season in high school baseball pitchers.[19] Ulnar nerve cross-sectional area significantly increased from 5 mm^2 to 6 mm^2 throughout the season, and the increase in cross-sectional area was associated with increased pitching workload.[19] However, the authors noted that ulnar neuritis may be contributing to increased cross-sectional area, which results from excessive traction on the ulnar nerve in the late cocking phase of pitching.[27] To better isolate the chronic adaptations to the ulnar nerve, the current study performed ultrasound evaluations at the beginning of spring training prior to the beginning of competitive games. While further research is needed to clarify, it is possible that ulnar nerve cross-sectional area primarily adapts acutely after pitching, but does not experience significant adaptations chronically.

Nerve circularity may also be affected by repetitive use and compression. For example, Liu et al.[28] developed a chronic sciatic nerve compression model in rats, demonstrating that the sciatic nerve decreases in diameter (i.e. flattens) due to chronic compression. In contrast, our study did not find adaptations to ulnar nerve circularity and cross-sectional area in professional pitchers. Possible explanations for why no flattening of the ulnar nerve was observed in the current study are that the cohort was healthy and asymptomatic, or possibly that the compressive force imposed upon the ulnar nerve is minimal. Echogenicity also did not quite reach significance bilaterally likely because of the healthy asymptomatic cohort utilized for this study. A study comparing echogenicity between various different axonal or demyelinating polyneuropathies and found that the ulnar nerve does experience changes in echogenicity based on type and severity of neuropathy, and that the nerve appears hypoechoic (darker) in patients with a stable or regressive disease course.[29] Plaikner et al.[30] further supports the potential for adaptations of ulnar nerve echogenicity in symptomatic patients by showing that patients with ulnar neuropathy are more likely to have a thickened, hyperechoic outer epineurium, which would present as increased echogenicity via ultrasound.

Interestingly, the results of the current study showed that subluxating ulnar nerves had a lower mean echogenicity than non-subluxating ulnar nerves. The authors originally hypothesized that subluxating ulnar nerves would appear hyperechoic due to increased stress on the ulnar nerve from the subluxation mechanism. However, it is possible that subluxation is instead removing tension/compression loads from the ulnar nerve. As the ulnar nerve moves around the medial epicondyle during elbow flexion, tensile and compression forces are expected to increase, however the ulnar nerve could relieve some of this force by subluxating and thus no longer being tightly hooked around the medial epicondyle similar to the result of a transposition. Enlargement of the hypoechoic fascicle would also be a possible explanation for why the subluxating ulnar nerves had lower echogenicity, however no differences in nerve cross-sectional area were observed, suggesting that swelling and/or hypertrophy was not increased due to subluxation. Further research eliciting a cadaveric model would be helpful in clarifying the mechanism of ulnar nerve subluxation and forces associated with subluxation in throwers.

Overall, clinicians should note that ulnar nerve echogenicity may increase in the throwing elbow of baseball pitchers, and that pitchers who experience ulnar nerve subluxations may have lower ulnar nerve echogenicity. With further research evaluating ulnar nerve properties in baseball pitchers, ulnar nerve echogenicity may prove to be a valuable measure to guide injury prevention and rehabilitation for baseball pitchers. However, studies evaluating ulnar nerve properties immediately after pitching, and studies comparing ulnar nerve properties between symptomatic and asymptomatic pitchers, are essential before strong clinical recommendations can be provided.

There are several limitations to this study. First, only healthy asymptomatic pitchers were evaluated. While studies comparing symptomatic and asymptomatic pitchers are essential to clarify the role that ulnar nerve properties play in the onset of symptoms, the authors believed that an initial study evaluating the chronic adaptations solely due to repetitive throwing without the effect of symptoms was an important initial step. Future research comparing symptomatic and asymptomatic pitchers will help clarify whether ulnar nerve adaptations contribute to elbow pain or injury, especially in pitchers with ulnar neuropathy. Also, only professional baseball pitchers were included. The findings of this study may not be applicable to younger and less experienced baseball pitchers, as workload, training, and availability of sports medicine staff differ tremendously based on level of play. Plus, sample sizes were limited when performing sub-analysis on pitchers with subluxation vs. those without subluxation. However, the means of circularity and cross-sectional area are very similar between both groups, so increased sample size may not change the statistical significance of these findings. Finally, the whole ulnar nerve and its surrounding epineurium were assessed together, thus specific regions of the ulnar nerve were not evaluated in isolation. It is possible that certain aspects of the ulnar nerve, such as the lateral aspect closest to the olecranon, experience more adaptation due to increased friction.

Conclusion

The ulnar nerve of the throwing elbow had similar cross-sectional area, echogenicity, and circularity compared to the non-dominant ulnar nerve. Nerve echogenicity was significantly decreased in subluxating ulnar nerves, however further research is necessary to determine why this difference exists and the potential direction of causality.

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Figure Legends

Figure 1. Ultrasound image showing a normal unsubluxated ulnar nerve.

*=ulnar nerve, ME=medial epicondyle, M=medial, L=lateral.

Figure 2. Ultrasound image showing a subluxated ulnar nerve.

*=ulnar nerve, ME=medial epicondyle, M=medial, L=lateral.

Table 1. Comparison of ulnar nerve ultrasound characteristics between the dominant and non-dominant elbows.

Ultrasound Variable	Dominant	Non-Dominant	Effect Size	P Value
Area (cm^2)	0.2 (0.1)	0.2 (0.1)	0.16	0.4
Echogenicity (pixel intensity)	137 (29)	128 (31)	0.29	0.07
Circularity	0.67 (0.11)	0.69 (0.12)	0.17	0.4

Data is presented as mean (standard deviation).

Table 2. Comparison of ulnar nerve ultrasound characteristics between elbows with vs. without ulnar nerve subluxation.

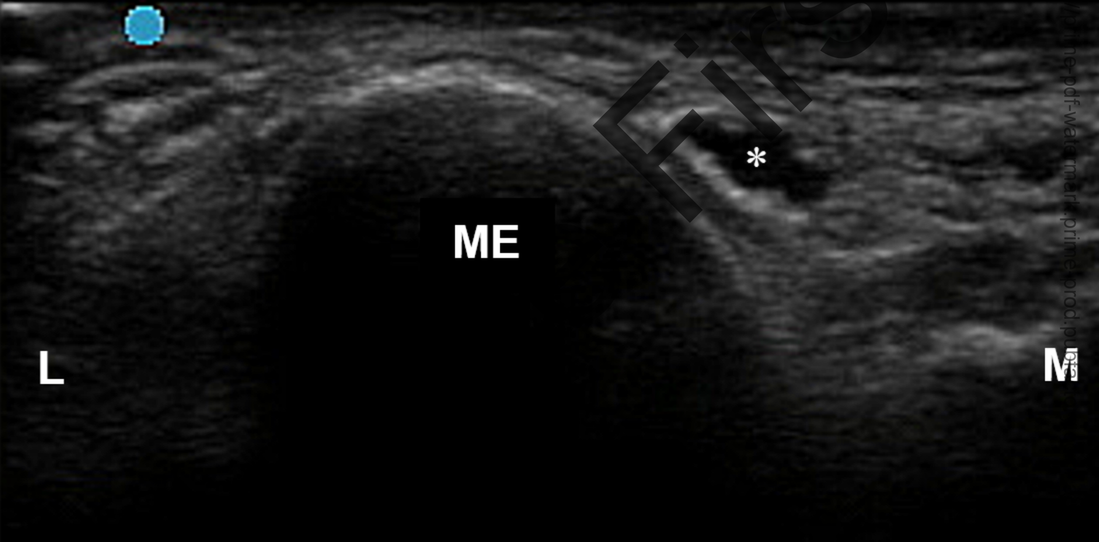
Ultrasound Variable	Nerve Subluxation (n=23)	No Nerve Subluxation (n=44)	P Value
Area (cm^2)	0.2 (0.0)	0.2 (0.0)	0.1
Echogenicity (pixel intensity)	127 (28)	143 (29)	**0.006**
Circularity	0.68 (0.09)	0.66 (0.12)	0.4

Data is presented as mean (standard deviation). Significant differences are in bold.

Table 3. The interaction effect between arm and ulnar nerve subluxation.

Ulnar Nerve	Dominant Arm	Non-Dominant Arm	P value
Cross-Sectional Area (cm^2)			
Subluxation	0.20 (0.05)	0.21 (0.04)	0.9
No Subluxation	0.21 (0.05)	0.22 (0.07)	
Echogenicity (pixel intensity)			
Subluxation	127 (28)	117 (23)	0.8
No Subluxation	143 (29)	134 (33)	
Circularity			
Subluxation	0.68 (0.09)	0.70 (0.10)	0.9
No Subluxation	0.66 (0.12)	0.68 (0.13)	

Data is presented as mean (standard deviation).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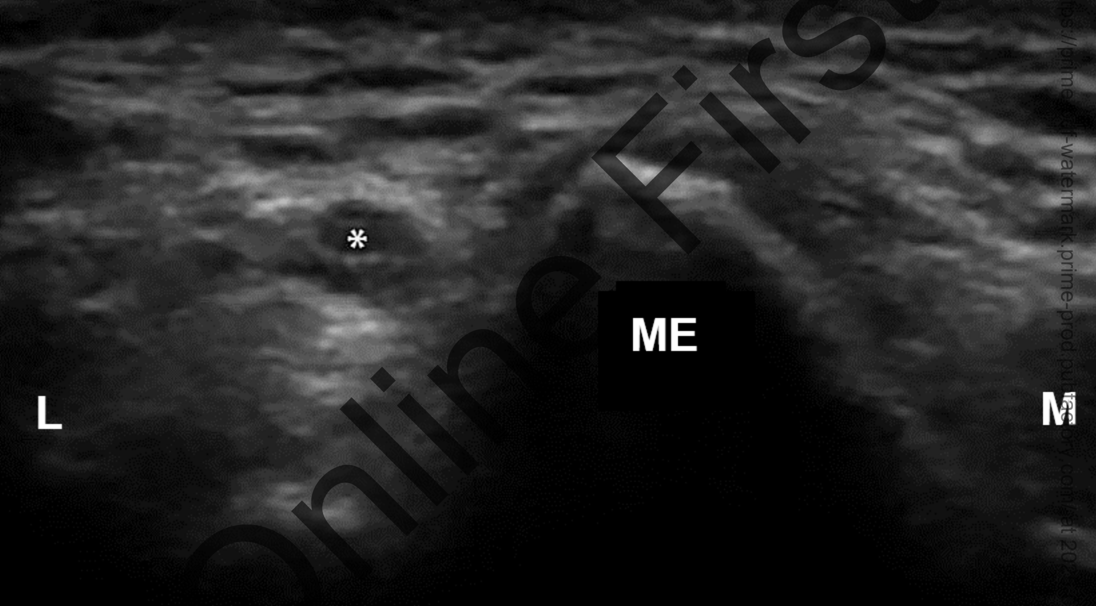
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