JSES International 5 (2021) 942–947

Contents lists available at ScienceDirect

JSES International

journal homepage: www.jsesinternational.org

The ultrasonographic assessment of the morphologic changes in the ulnar nerve at the cubital tunnel in Japanese volunteers: relationship between dynamic ulnar nerve instability and clinical symptoms

Fumitaka Endo, MD[a], Tsuyoshi Tajika, MD, PhD[b,*], Takuro Kuboi, MD[a], Satoshi Shinagawa, MD, PhD[a], Toshiki Tsukui, MD[a], Tomoki Nakajima, MD[a], Yusuke Kogure, MD[a], Hirotaka Chikuda, MD, PhD[a]

[a]*Department of Orthopaedic Surgery, Gunma University Graduate School of Medicine, Maebashi, Gunma, Japan*
[b]*Graduate School of Health Sciences, Gunma University, Maebashi, Gunma, Japan*

ARTICLE INFO

Keywords:
Ulnar nerve
Instability
Cross-sectional area
Dynamic ultrasound
Cubital tunnel
Patient-Rated Elbow Evaluation

Level of evidence: Level III; Cross-Sectional Design; Epidemiology Study

Background: We investigated the differences in the prevalence of ulnar nerve instability (UNI) by hand dominance and evaluated the relationship between UNI and morphologic changes in the ulnar nerve and the clinical findings and upper limb function.
Methods: This study examined 153 healthy participants (n = 306 elbows; 44 men, 112 women; mean age 65.4 years) who underwent ultrasonography to assess the ulnar nerve cross-sectional area (UNCSA) at three points of the bilateral cubital tunnel at 30° of elbow flexion. Participants were divided into three groups based on the ultrasonography findings of UNI: no instability (type N), subluxation (type S), and dislocation (type D). For the dominant and nondominant sides, we assessed the relationship between the UNCSA and clinical factors, including the age, gender, height, weight, body mass index, fat mass, grip strength, key pinch strength, UNCSA, and Patient-Rated Elbow Evaluation score.
Results: We identified 75 cases without instability in both elbows and 78 cases with some instability. The prevalence of UNI was 51%. No significant difference was found between hand dominance and the prevalence of UNI. The UNCSA at 1 cm proximal to the medial epicondyle on the bilateral sides in type S was the most increased among three types.
Conclusion: UNI was identified in almost half of the participants, with no marked difference found in the hand dominance. The UNCSA at 1 cm proximal to the medial epicondyle was significantly increased the most in type S. UNI does not appear to be associated with elbow symptoms in the general population.

Ulnar nerve instability (UNI) at the elbow has been reported in asymptomatic healthy subjects.[1,8] The frequency of UNI at the elbow is reported to be 2%-51%.[1,2,4,6,8–10,17,22,24] Classification of UNI has been described for the ulnar nerve shifting incompletely onto the medial condyle as subluxation and the ulnar nerve translating completely over the medial condyle as dislocation.[1,8,17] The frequency of subluxation is reported to be about 5.7%-27%, while that of dislocation is 2%-31%.[1,2,4,6,8–10,17,24]

Elbow flexion induces subluxation and dislocation of the ulnar nerve at the cubital tunnel. Repetitive ulnar nerve hypermobility with elbow flexion might induce shear stress to the ulnar nerve when the nerve is rubbed with the edge of the humeral medial epicondyle (ME).[8,17] Such shear stress might cause ulnar neuropathy at the cubital tunnel. Some studies have demonstrated UNI as a risk factor for ulnar nerve neuropathy (UNE).[11,18,20] However, others have found no association with the presence of UNI and clinical symptom of UNE.[2,4,24]

Repetitive dynamic friction stress might induce morphologic changes in the ulnar nerve because of intraneural edema,[12] possibly inducing an increase in the cross-sectional area (CSA) of the ulnar nerve (UNCSA), as reported in patients with entrapment neuropathy, such as carpal tunnel syndrome and cubital tunnel syndrome (CuTS).[3,14,15,22,23,25] Nevertheless, the relationship between UNI and morphologic changes in the ulnar nerve and clinical findings remains unclear.

Hand dominance might influence the laterality of the upper limb function and elbow joint conditions and the prevalence of UNI in the general population. Ultrasonography (US) has been shown to be useful for detecting dynamic UNI and measurements of the

Institutional Review Board approval was received from Gunma University Graduate School of Medicine (no. 2017-135).

*Corresponding author: Tsuyoshi Tajika, MD, PhD, Graduate School of Health Sciences, Gunma University. 3-39-22 Showa-machi, Maebashi, Gunma 371-8514, Japan.

E-mail address: tajika@gunma-u.ac.jp (T. Tajika).

https://doi.org/10.1016/j.jseint.2021.05.005

enlarged UNCSA, as reported from earlier studies.[4,7,9−11,13,14,17−20,23,24] We hypothesized that hand dominance influences the prevalence of UNI and that the extent of UNI is correlated with the increase in the CSA of the ulnar nerve and subjective and objective clinical findings in the general population.

The present study used US to investigate the differences in the prevalence of UNI with dynamic elbow flexion by hand dominance and to evaluate the relationship between UNI as well as morphologic changes in the ulnar nerve and the clinical findings and upper limb function.

Materials and methods

Participants

Medical examinations of residents of a mountain village in Japan (total population of 4,410, comprising 2164 men and 2246 women in 2019) are regularly conducted for the early detection of cancer and to prevent lifestyle-related diseases. The age of eligibility for the medical examination is at least 20 years. In that village, agro-forestry and tourism are the main industries.

In 2019, 956 people (427 men, 529 women) underwent medical examinations. Of these 956 residents, 160 (46 men, 114 women; mean age 65.4 years; range, 20-88 years) underwent an orthopedic examination for this study by their own choice. Each had completed a self-administered questionnaire with items related to gender and their dominant hand. Participants agreed to inclusion in the study after being informed that their data would be published if they gave their consent to participate. We excluded participants with certain medical conditions, such as those who had already been diagnosed with CuTS, those who had received surgical treatment for CuTS, those who had a history of elbow trauma, and those who had any systemic disorder, such as diabetes mellitus, connective tissue disorders, and polyneuropathy. (Fig. 1). The data of the remaining 153 participants (306 elbows) who were not receiving upper limb treatment in a medical facility at that time were therefore assessed for this study.

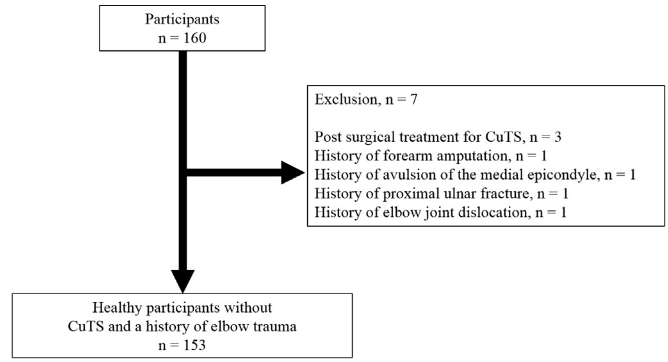

Figure 1 Flowchart of the participants in this study. CuTS, cubital tunnel syndrome.

The assessment of the elbow function and symptoms

We evaluated the elbow function and symptoms using the Japanese version of the Patient-Rated Elbow Evaluation (PREE-J). The elbow pain score, function score, and total score were evaluated. After Hanyu et al evaluated the reliability, validity, and responsiveness of PREE-J, they reported that it had an equivalent evaluation capacity to that of the original PREE.[5]

Anthropometric measurements

Height was measured using a digital height meter (A&D Corp., Tokyo, Japan). Body composition was measured using a multifrequency segmental body composition analyzer (MC780U; Tanita Corp., Tokyo, Japan), including assessments of the body weight, body mass index, and fat mass.

Grip and key pinch strength measurements

A digital dynamometer (Takei Scientific Instruments Co., Tokyo, Japan) was used to measure the grip strength. We used a pinch gauge (MG-4320NC pinch gauge; B & L Engineering, Santa Ana, CA, USA) to measure the key pinch strength of both the dominant and nondominant sides. Grip testing was performed using a standardized position recommended by the American Society of Hand Therapists.

Subjects were seated with their shoulder in adduction and neutral rotation, the elbow flexed at 90°, the forearm in a neutral position, and the wrist between 0° and 30° extension and 0° and 15° ulnar deviation. Pinch testing was performed with the shoulder, elbow, forearm, and wrist in a neutral position. Key pinch was assessed by pressing the thumb pad to the lateral aspect of the middle phalanx of the index finger. For each grip and key pinch test, two measurements were taken for both the dominant and nondominant sides. All tests were administered by a single orthopedic surgeon. The average of two trials for each grip strength and key pinch strength value was used for the data analysis.

US and determination of the CSA of the ulnar nerve and UNI

We performed US examinations of the bilateral elbows in all participants. We used a Logiq e premium ultrasound system (GE Healthcare UK, Ltd., Buckinghamshire, UK) with a 10-MHz linear array transducer. An orthopedic surgeon (F.E.) with more than eight years of experience in carrying out US and surgery performed the US examinations.

Participants were seated facing the examiner to maintain a position with the shoulder in slight flexion, the elbow joint at 30° flexion, and the forearm in the supinated position. The examiner held the probe perpendicular to the skin and adjusted the angle to obtain short-axis views of the ulnar nerve. The probe was placed on the skin with minimum pressure (Fig. 2*A*). The nerve was traced proximally to distally over the medial skin around the elbow. The ME segment level was established by identifying the top of the humeral ME. Terayama et al reported that the UNCSA was significantly larger in the group with UNE at the elbow than in controls at 4 to 1 cm proximal to the ME, at the ME, and at 1 to 5 cm distal to the ME (Fig. 2*B*); in addition, they also reported that the maximum UNCSA was observed at 1 cm proximal to the ME.[23] While referencing their report, we defined 3 levels: 4 cm and 1 cm proximal to the ME and 5 cm distal to the ME. Based on the short-axis US views of the ulnar nerve, manually traced areas along the outside edge of the hypoechoic rims of the fascicles of the ulnar nerve were defined as the UNCSA (Fig. 2*C*).[14]

After the examination of the UNCSA, without changing the shoulder position, the elbow was maximally flexed, and then, the UNI was evaluated. The maximum elbow flexion varied for each patient, depending on their body habitus, but was always passively fully flexed (at least 90°).

The ulnar nerve position was ascertained as per the classification reported by Okamoto et al: type N (no instability), type S (subluxation), or type D (dislocation).[17] In type N, the ulnar nerve moves in an anteromedial direction but does not reach the tip of the

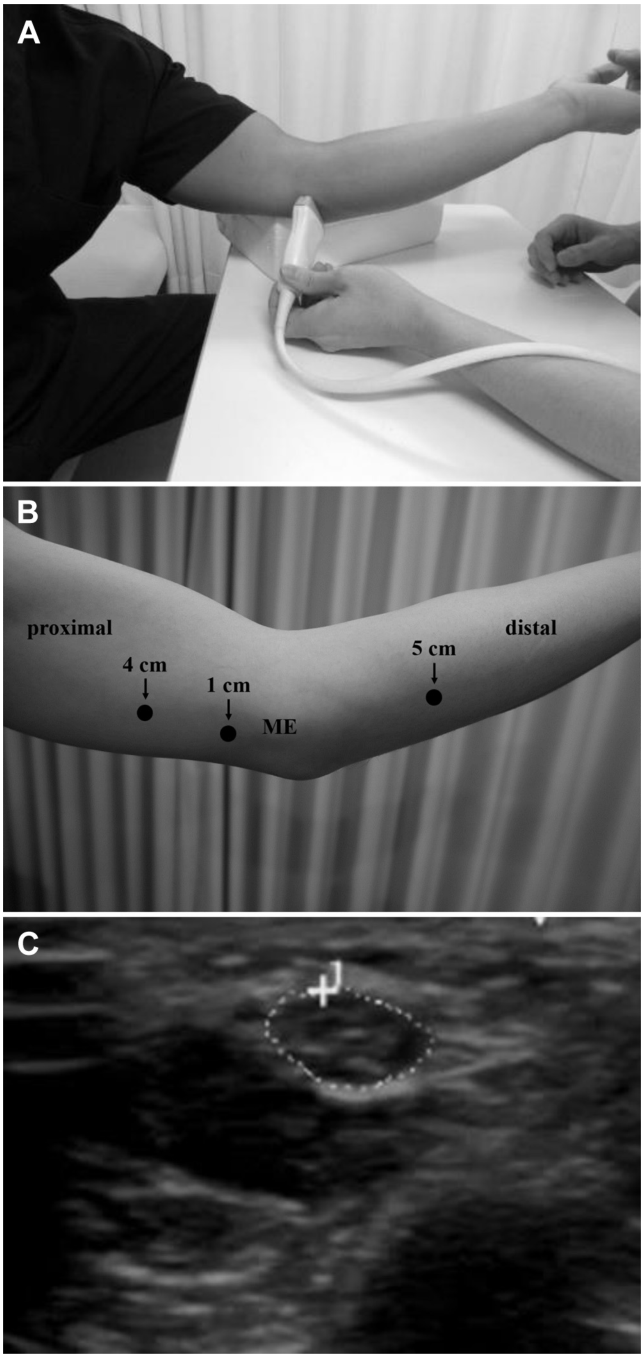

Figure 2 (**A**) Subject position during the ultrasonographic examination of the left ulnar nerve in the cubital tunnel. (**B**) Point of scanning of ulnar nerve by ultrasonography. We defined three levels at 4 cm and 1 cm proximal to the ME and 5 cm distal to the ME. (**C**) Transversal scan with measurement of the CSA of the ulnar nerve. Based on the short-axis US views of the ulnar nerve, manually traced areas along the outside edge of the hypoechoic rims of the fascicles of the ulnar nerve were defined as the ulnar nerve CSA. *CSA*, cross-sectional area; *ME*, medial epicondyle.

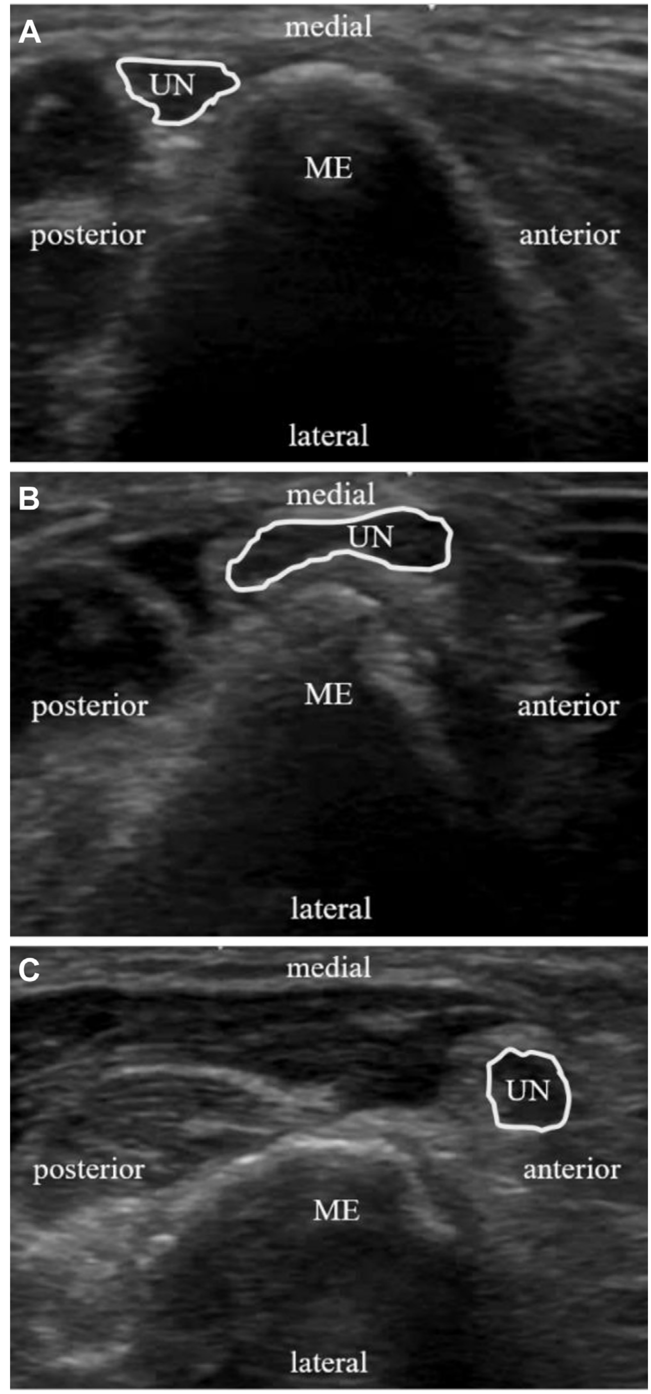

Figure 3 (**A**) Transverse US views of the ulnar nerve showing normal findings. (**B**) Transverse US views of the ulnar nerve showing subluxation. (**C**) Transverse US views of the ulnar nerve showing dislocation. *ME*, medial epicondyle; *UN*, ulnar nerve; *US*, ultrasonography.

epicondyle (Fig. 3*A*). In type S, there is subluxation. The nerve moves onto the tip of the epicondyle (Fig. 3*B*). In type D, there is dislocation. The ulnar nerve crosses over the tip of the epicondyle (Fig. 3*C*). The participants were asked whether or not they had symptoms of intermittent paresthesia, numbness, and tingling in their pinkie and ulnar half of the ring finger during elbow flexion.

Statistical analyses

After data collection was completed, we stratified participants who had no dislocation of the ulnar nerve in the elbow into the type N group, those who had subluxation of the ulnar nerve into the type S group, and those who had dislocation of the ulnar nerve in the elbow into the type D group on the dominant and nondominant sides. Using an analysis of variance or Steel-Dwass test, we compared the age, height, weight, body mass index, grip strength,

Table 1
Prevalence by type of ulnar nerve instability in the bilateral extremities.

Laterality of ulnar nerve	Number	Prevalence
Bilateral normal	75	49.0%
Unilateral subluxation	23	15.0%
Unilateral dislocation	4	2.6%
Bilateral subluxation	23	15.0%
Bilateral dislocation	12	7.9%
Unilateral subluxation and unilateral dislocation	16	10.5%

key pinch strength, fat mass percentage, UNCSA at 4 cm and 1 cm proximal to the ME, UNCSA at 5 cm distal to the ME, PREE Pain score, PREE Functional score, and PREE Total score among the 3 groups. The gender differences in the three subject groups were compared using a chi-square test.

Data are presented as the mean and standard deviation. A P value of <.05 was inferred to be statistically significant. This study was approved by the regional ethics board.

Results

We evaluated 75 cases without instability and 78 cases with some instability in both elbows. The prevalence of UNI was 51% in 153 participants (Table I). No subjects had intermittent paresthesia, numbness, or tingling in the pinkie finger or ulnar half of the ring finger during elbow flexion.

The evaluation of all 306 elbows revealed 177 elbows to be type N (57.8%), 85 elbows to be type S (27.8%), and 46 elbows to be type D (15.4%). Regarding the participant number distribution of the status of the UNI, no significant differences were found between the dominant side and nondominant side ($P = .52$). The intraobserver and interobserver reliability for US measurements of the UNCSA was 0.95 and 0.91, respectively. No significant difference was found among the three groups in terms of the age, height, weight, body mass index, grip strength, key pinch strength, fat mass percentage, UNCSA at 4 cm or UNCSA at 5 cm distal to the ME, PREE-J Pain score, PREE-J Functional score, or PREE-J Total score for either the dominant or nondominant side (Tables II and III). The UNCSA at 1 cm proximal to the ME in the type S group on both the dominant and nondominant sides was significantly increased, reaching the highest value among the three groups (Tables II and III).

Discussion

This study yielded three main findings. First, the prevalence of UNI was 51% (78 cases with some instability in both elbows) in 153 participants, with subluxation found in 85 elbows (27.8%) and dislocation in 46 elbows (15.4%) among the total 306 elbows. Earlier reports described different prevalences of 15.4%-30% for subluxation and 5.8%-31% for dislocation of the ulnar nerve at the cubital tunnel.[1,2,4,6,8–10,17,24] Cornelson et al[4] found UNI in 56% (25% subluxation, 31% dislocation) of 84 elbows among healthy volunteers 22-40 years of age by US and speculated that the inclusion of many athletes among their research subjects might have led to a much higher prevalence of UNI than seen in earlier studies.[1,2,6,8–10,17,24] Our percentage of UNI, as evaluated among general participants with a wide range of age groups, was similar to the results reported by Cornelson et al.[4] We hypothesized that UNI symptoms are influenced by the frequency of using the upper limbs, which is associated with hand dominance. However, our data confirmed the results reported by Calfee et al, whose study demonstrated no association with UNI symptom or hand dominance.[2] These results might indicate that UNI is not uncommon among the general population and that UNI is not attributable to hand dominance.

Second, no significant difference was found in the present study between the degree of UNI and the subjective clinical elbow symptoms evaluated by the PREE and grip strength as well as key pinch strength. The relationship between UNI and UNE is controversial.[2,4,11,18,20,24] Calfee et al reported that elbows with nerve hypermobility did not show a higher prevalence of subjective symptoms (snapping, pain, or tingling) than the elbows without hypermobility.[2] Omejec and Podnar[18] reported that ulnar nerve dislocation tended to be more common in controls than in patients with UNE. The age range of our survey subjects was wider than that of populations studied in previous reports. This may support the generalizability of our findings concerning the lack of a relationship between UNI and UNE. Our data might confirm the asymptomatic characteristic of UNI, similarly to earlier research results.[2,18]

Third, our results revealed that UNCSA at 1 cm proximal to the ME in the type S group on both the dominant and nondominant sides was increased the most significantly among the three groups (dominant side: type N, 7.6 ± 1.9 cm^2; type S, 9.7 ± 2.4 cm^2; type D, 7.3 ± 1.6 cm^2; $P < .001$; Nondominant side: type N, 7.4 ± 1.8 cm^2; type S, 9.4 ± 2.8 cm^2; type D, 7.7 ± 1.4 cm^2; $P < .001$). Cornelson et al[4] reported significantly more frequent UNCSA at the cubital tunnel in subjects with UNI than in controls. Okamoto et al[17] reported that UNI produces frictional forces and increased compression against the hard convex of the medial epicondyle. Subluxation of the ulnar nerve, compressed between the ME and soft tissues, might induce intraneural edema and result in a marked increase in the UNCSA. Of note, Terayama et al[23] demonstrated that a cutoff threshold of 11 mm^2 for the UNCSA at 1 cm proximal to the ME was useful for diagnosing UNE by US. However, the subjects in the study by Terayama et al were few in number, with a small age range and all men. Further longitudinal studies will be necessary to clarify whether or not UNI develops in asymptomatic subjects with ulnar nerve subluxation and an increased UNCSA.

Several limitations associated with the present study warrant mention. First, the study was conducted using a cross-sectional design, which might not provide definitive information about cause-and-effect relations. Second, we did not perform physical examinations, such as evaluations for Tinel sign at the cubital tunnel or an elbow flexion test or shoulder internal test, or any electrophysiological tests among the participants.[16] Our study might therefore have included participants with occult CuTS. Third, the sensory symptoms of our participants were assessed using a self-reported questionnaire without any objective clinical evaluations, such as the Semmes-Weinstein monofilament test or two-point discrimination. Fourth, only a few individuals 20-40 years of age participated in the study. The age distribution might therefore have influenced our results. Fifth, we did not evaluate the muscle volume or the degree movement of the medial triceps, which might induce ulnar instability when the medial triceps moves anteriorly with elbow flexion.[13] Sixth, we did not assess the carrying angle, which might influence the ulnar instability with elbow flexion.[21] Finally, the intraobserver and interobserver reliability for US measurements of UNCSA was 0.95 and 0.91, respectively, showing the interobserver reliability to be lower than the intraobserver reliability. US measurements of the UNCSA may have been influenced by the US performance of the observers.

Conclusion

There were 75 cases without instability in both elbows and 78 with some instability. The prevalence of UNI was 51%. No subjects had symptoms of intermittent paresthesia, numbness, or tingling in

Table 2
The comparison of data by type of ulnar nerve instability on the dominant side.

Variable	Type N ($n = 92$)	Type S ($n = 38$)	Type D ($n = 23$)	P
Age, (yr)	65.4 (14.2)	65.1 (14.6)	64.4 (13.1)	.96
Height (cm)	154.0 (9.4)	156.6 (12.0)	157.4 (9.5)	.21
Weight (kg)	54.4 (9.7)	56.9 (10.8)	57.7 (13.6)	.28
Sex (n)				.10
Men	19	13	9	
Women	73	25	14	
BMI (kg/m^2)	22.9 (3.7)	23.3 (4.2)	23.0 (3.4)	.92
Fat mass (%)	29.3 (8.8)	26.1(9.5)	26.8 (6.2)	.14
Grip strength (kg)	24.6 (7.2)	28.0 (9.6)	27.6 (9.2)	.10
Key pinch strength (kg)	6.9 (1.8)	7.7 (2.4)	7.7 (2.4)	.15
UNCSA (4 cm proximal) (mm^2)	5.7 (1.3)	5.7(1.3)	6.0 (1.4)	.39
UNCSA (1 cm proximal) (mm^2)	7.6 (1.9)	9.7 (2.4)*,†	7.3 (1.6)	<.001
UNCSA (5 cm distal) (mm^2)	4.2 (1.0)	4.3 (1.1)	4.2 (0.9)	.90
PREE-J Pain score	1.7 (5.4)	1.3 (4.1)	2.0 (5.4)	.94
PREE-J Function score	0.4 (1.8)	0.2 (0.7)	0.2 (0.7)	.96
PREE-J Total score	2.0 (6.6)	1.5 (4.7)	2.2 (6.0)	.90

BMI, body mass index; *PREE-J*, Japanese version of the Patient-Rated Elbow Evaluation; *UNCSA*, cross sectional area of the ulnar nerve.
Mean values are shown with the standard deviation in parentheses.
Statistically significant: $P < .05$.
*Significantly different ($P < .001$) from the values in the type N group.
†Significantly different ($P < .001$) from the values in the type D group.

Table 3
The comparison of data by type of ulnar nerve instability on the nondominant side.

Variable	Type N ($n = 85$)	Type S ($n = 47$)	Type D ($n = 21$)	P
Age (yr)	67.0(14.4)	63.1(13.2)	62.6(13.2)	.09
Height (cm)	154.0 (10.6)	157.5 (9.9)	157.2 (8.0)	.12
Weight (kg)	54.2 (9.9)	57.8 (10.9)	55.6 (12.3)	.17
Sex (n)				.69
Men	23	11	7	
Women	62	36	14	
BMI (kg/m^2)	23.0 (3.9)	23.3 (3.5)	22.3 (3.2)	.60
Fat mass (%)	29.0 (8.9)	27.6 (8.8)	25.8 (7.6)	.32
Grip strength (kg)	24.4 (7.7)	27.7 (10.8)	24.9 (8.9)	.28
Key pinch strength (kg)	6.7 (2.0)	7.2 (2.3)	6.9 (2.1)	.56
UNCSA (4 cm proximal) (mm^2)	5.6 (1.1)	5.7(1.0)	6.0 (1.3)	.43
UNCSA (1 cm proximal) (mm^2)	7.4 (1.8)	9.4 (2.8)*,†	7.7 (1.4)	<.001
UNCSA (5 cm distal) (mm^2)	4.3 (0.9)	4.2 (0.8)	4.2 (0.9)	.78
PREE Pain	1.6 (5.3)	2.2 (5.1)	1.0 (4.2)	.33
PREE Function	0.3 (1.8)	0.2 (0.6)	0.2 (0.9)	.77
PREE Total	1.9 (6.6)	2.4 (5.5)	1.1 (5.0)	.39

BMI, body mass index; *PREE-J*, Japanese version of the Patient-Rated Elbow Evaluation; *UNCSA*, cross sectional area of the ulnar nerve.
Mean values are shown with the standard deviation in parentheses.
Statistically significant: $P < .05$.
*Significantly different ($P < .001$) from the values in the type N group.
†Significantly different ($P < .001$) from the values in the type D group.

the pinkie finger, or ulnar half of the ring finger during elbow flexion. The proportion with UNI at the cubital tunnel level was 42.2% (27.8% subluxation, 15.4% dislocation) among 306 elbows of volunteers who were not receiving upper limb treatment in a medical facility. The UNCSA at 1 cm proximal to the ME in the type S (subluxation) group on both the dominant and non-dominant sides was increased significantly the most among type N (no instability) and type D (dislocation). No significant difference was found between the dominant and nondominant hands in the prevalence of UNI. UNI does not appear to be associated with elbow symptoms in the general population.

Disclaimers:

Funding: No funding was disclosed by the author(s).
Conflicts of interest: The authors, their immediate families, and any research foundations 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.

References

1. Ashenhurst EM. Anatomical factors in the etiology of ulnar neuropathy. Can Med Assoc J 1962;87:159-63.
2. Calfee RP, Manske PR, Gelberman RH, Van Steyn MO, Steffen J, Goldfarb CA. Clinical assessment of the ulnar nerve at the elbow: reliability of instability testing and the association of hypermobility with clinical symptoms. J Bone Joint Surg Am 2010;92:2801-8. https://doi.org/10.2106/JBJS.J.00097.
3. Carter GT, Weiss MD, Friedman AS, Allan CH, Robinson L. Diagnosis and treatment of Work-related ulnar neuropathy at the elbow. Phys Med Rehabil Clin N Am 2015;26:513-22. https://doi.org/10.1016/j.pmr.2015.04.002.
4. Cornelson SM, Sclocco R, Kettner NW. Ulnar nerve instability in the cubital tunnel of asymptomatic volunteers. J Ultrasound 2019;22:337-44. https://doi.org/10.1007/s40477-019-00370-9.
5. Hanyu T, Watanabe M, Masatomi T, Nishida K, Nakagawa T, Nishiura Y, et al. Reliability, validity, and responsiveness of the Japanese version of the patient-rated elbow evaluation. J Orthop Sci 2013;18:712-9. https://doi.org/10.1007/s00776-013-0408-z.
6. Husarik DB, Saupe N, Pfirrmann CW, Jost B, Holder J, Zanetti M. Elbow nerves: MR findings in 60 asymptomatic subjects – normal anatomy, variants, and pitfalls. Radiology 2009;252:148-56. https://doi.org/10.1148/radiol.2521081614.
7. Kang JH, Joo BE, Kim KH, Park BK, Cha J, Kim DH. Ultrasonographic and electrophysiological evaluation of ulnar nerve instability and snapping of the

triceps medial Head in healthy subjects. Am J Phys Med Rehabil 2017;96:e141-6. https://doi.org/10.1097/PHM.0000000000000706.
8. Kawahara Y, Yamaguchi T, Honda Y, Tomita Y, Uetani M. The ulnar nerve at elbow extension and flexion: assessment of position and signal Intensity on MR Images. Radiology 2016;280:483-92. https://doi.org/10.1148/radiol.2016150173.
9. Kim BJ, Date ES, Lee SH, Yoon JS, Hur SY, Kim SJ. Distance measure error induced by displacement of the ulnar nerve when the elbow is flexed. Arch Phys Med Rehabil 2005;86:809-12. https://doi.org/10.1016/j.apmr.2004.08.006.
10. Kim BJ, Koh SB, Park KW, Kim SJ, Yoon JS. Pearls & Oy-sters: false positives in short-segment nerve conduction studies due to ulnar nerve dislocation. Neurology 2008;70:9-13. https://doi.org/10.1212/01.wnl.0000297515.86197.2e.
11. Leis AA, Smith BE, Kosiorek HE, Omejec G, Podnar S. Complete dislocation of the ulnar nerve at the elbow: a protective effect against neuropathy? Muscle Nerve 2017;56:242-6. https://doi.org/10.1002/mus.25483.
12. Lundborg G, Myers R, Powell H. Nerve compression injury and increased endoneurial fluid pressure: a “miniature compartment syndrome”. J Neurol Neurosurg Psychiatry 1983;46:1119-24.
13. Michael AE, Young P. Is triceps hypertrophy associated with ulnar nerve luxation? Muscle Nerve 2018;58:523-7. https://doi.org/10.1002/mus.26183.
14. Mondelli M, Filippou G, Frediani B, Aretini A. Ultrasonography in ulnar neuropathy at the elbow: relationships to clinical and electrophysiological findings. Neurophysiol Clin 2008;38:217-26. https://doi.org/10.1016/j.neucli.2008.05.002.
15. Nakamichi K, Tachibana S. Ultrasonographic measurement of median nerve cross-sectional area in idiopathic carpal tunnel syndrome: Diagnostic accuracy. Muscle Nerve 2002;26:798-803. https://doi.org/10.1002/mus.10276.
16. Ochi K, Horiuchi Y, Tanabe A, Morita K, Takeda K, Ninomiya K. Comparison of shoulder internal rotation test with the elbow flexion test in the diagnosis of cubital tunnel syndrome. J Hand Surg Am 2011;36:782-7. https://doi.org/10.1016/j.jhsa.2010.12.019.
17. Okamoto M, Abe M, Shirai H, Ueda N. Morphology and dynamics of the ulnar nerve in the cubital tunnel. Observation by ultrasonography. J Hand Surg Br 2000;25:85-9.
18. Omejec G, Podnar S. Does ulnar nerve dislocation at the elbow cause neuropathy? Muscle Nerve 2016;53:255-9. https://doi.org/10.1002/mus.24786.
19. Ozturk E, Sonmez G, Colak A, Sildiroglu HO, Mutlu H, Senol MG, et al. Sonographic appearances of the normal ulnar nerve in the cubital tunnel. J Clin Ultrasound 2008;36:325-9. https://doi.org/10.1002/jcu.20486.
20. Schertz M, Mutschler C, Masmejean E, Silvera J. High-resolution ultrasound in etiological evaluation of ulnar neuropathy at the elbow. Eur J Radiol 2017;95:111-7. https://doi.org/10.1016/j.ejrad.2017.08.003.
21. Spinner RJ, O'Driscoll SW, Davids JR, Goldner RD. Cubitus varus associated with dislocation of both the medial portion of the triceps and the ulnar nerve. J Hand Surg Am 1999;24:718-26.
22. Tajika T, Kobayashi T, Yamamoto A, Kaneko T, Takagishi K. Diagnostic utility of sonography and correlation between sonographic and clinical findings in patients with carpal tunnel syndrome. J Ultrasound Med 2013;32:1987-93. https://doi.org/10.7863/ultra.32.11.1987.
23. Terayama Y, Uchiyama S, Ueda K, Iwakura N, Ikegami S, Kato Y, et al. Optimal measurement level and ulnar nerve cross-sectional area cutoff threshold for identifying ulnar neuropathy at the elbow by MRI and ultrasonography. J Hand Surg Am 2018;43:529-36. https://doi.org/10.1016/j.jhsa.2018.02.022.
24. Van Den Berg PJ, Pompe SM, Beekman R, Visser LH. Sonographic incidence of ulnar nerve (sub)luxation and its associated clinical and electrodiagnostic characteristics. Muscle Nerve 2013;47:849-55. https://doi.org/10.1002/mus.23715.
25. Yayama T, Kobayashi S, Nakanishi Y, Uchida K, Kokubo Y, Miyazaki T, et al. Effects of graded mechanical compression of rabbit sciatic nerve on nerve blood flow and electrophysiological properties. J Clin Neurosci 2010;17:501-5. https://doi.org/10.1016/j.jocn.2009.07.110.