A new quantitative evaluation system for distal radioulnar joint instability using a three-dimensional electromagnetic sensor

Shintaro Mukohara (no.8shintaro@gmail.com)
Kobe University Graduate School of Medicine School of Medicine: Kobe Daigaku Daigakuin Igakukei Kenkyuka Igakubu
Yutaka Mifune
Kobe University Graduate School of Medicine School of Medicine: Kobe Daigaku Daigakuin Igakukei Kenkyuka Igakubu
Atsuyuki Inui
Kobe University Graduate School of Medicine School of Medicine: Kobe Daigaku Daigakuin Igakukei Kenkyuka Igakubu
Hanako Nishimoto
Kobe University Graduate School of Medicine School of Medicine: Kobe Daigaku Daigakuin Igakukei Kenkyuka Igakubu
Kohei Yamaura
Kobe University Graduate School of Medicine School of Medicine: Kobe Daigaku Daigakuin Igakukei Kenkyuka Igakubu
Tomoya Yoshikawa
Kobe University Graduate School of Medicine School of Medicine: Kobe Daigaku Daigakuin Igakukei Kenkyuka Igakubu
Issei Shinohara
Kobe University Graduate School of Medicine School of Medicine: Kobe Daigaku Daigakuin Igakukei Kenkyuka Igakubu
Yuichi Hoshino
Kobe University Graduate School of Medicine School of Medicine: Kobe Daigaku Daigakuin Igakukei Kenkyuka Igakubu
Kouki Nagamune
University of Fukui: Fukui Daigaku
Ryosuke Kuroda
Kobe University Graduate School of Medicine School of Medicine: Kobe Daigaku Daigakuin Igakukei Kenkyuka Igakubu

Research Article

Keywords: Distal radioulnar joint, Instability, Dynamic instability, Electromagnetic sensor system, Triangular fibrocartilage complex injury, TFCC injury

Posted Date: May 13th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-518290/v1

Version of Record: A version of this preprint was published at Journal of Orthopaedic Surgery and Research on July 14th, 2021. See the published version at https://doi.org/10.1186/s13018-021-02601-4.

Abstract

Background

The accurate assessment of distal radioulnar joint (DRUJ) instability is still challenging as there is no established objective evaluation method. This study aimed to develop a noninvasive measurement method using a three-dimensional electromagnetic sensor system (EMS) to quantitatively assess and characterize the normal DRUJ movement in healthy volunteers.

Methods

The DRUJ movement was mimicked using both a block model and saw bone. Movement of the models was measured by EMS, and the accuracy and reproducibility of the measurements were assessed. The movement was evaluated in 14 healthy volunteers (7 men and 7 women) by three hand surgeons. Measurement was done in a sitting position with the elbow flexed and the forearm pronated. One sensor each was attached to the distal radial shaft and the ulnar head. The examiners fixed the distal radius and moved the ulnar head from the dorsal to the volar side, measuring the dorsovolar ulnar head translation. The intraclass and interrater correlation coefficients (ICCs) were calculated using the average values of the measurements. The differences between the dominant and non-dominant sides and between men and women were also assessed.

Results

The accuracy and reproducibility assessment results of the EMS showed high accuracy and reproducibility. The ICC (1,5) for the intra-rater reliability was 0.856, and the ICC (2,5) for inter-rater reliability was 0.868. The mean ulnar head translation and difference between dominant and non-dominant sides were 6.00 ± 1.16 mm (Mean ± SD) and -0.12 ± 0.40 mm, respectively. There were no significant differences between any of the parameters.

Conclusions

A new measurement method using EMS could evaluate DRUJ movement with high accuracy, reproducibility, and intra- and inter-rater reliability. In healthy volunteers, the dorsovolar ulnar head translation was 6.00 mm. The difference between the dominant and non-dominant sides was < 1.0 mm with no significant difference. EMS provided an objective, non-invasive, real-time assessment of dynamic changes in the DRUJ. These findings could be useful in the treatment of patients with DRUJ instability.

Background

The stability of the distal radioulnar joint (DRUJ) is provided by the contour of the bones as well as the surrounding ligaments and muscles, such as the triangular fibrocartilage complex (TFCC), ulnocarpal ligament complex, extensor carpi ulnaris tendon and tendon sheath, the pronator quadratus muscle, the interosseous membrane including the interosseous ligament, and the capsule[1-5]. The TFCC particularly contributes to its stability, and TFCC injuries cause instability of the DRUJ, leading to chronic ulnar wrist pain[6,7]. Various manual tests for assessing DRUJ instability have been reported, such as the ballottement test, Piano key test, and Pisiform boot test. Some reports suggest that the ballottement test is the most reliable[8]; however, these manual tests depend on subjective evaluations. It is difficult to accurately assess instability in clinical practice, and there is no well-established method to objectively evaluate DRUJ instability.

Recently, a knee motion quantitative assessment method with high reproducibility using a three-dimensional electromagnetic sensor system (EMS) was reported[9-16]. This system can quantitatively evaluate knee laxity after anterior cruciate ligament (ACL) injury with a high sampling rate during the Lachman test and the pivot shift test, which have been used as manual examination methods for detecting ACL deficiency[9-16]. We hypothesized that EMS could be used to quantitatively evaluate DRUJ instability. Furthermore, it is important to establish a normal range to define DRUJ instability. Thus, the purpose of this study was to develop a new objective evaluation method for DRUJ instability using EMS, and to quantitatively evaluate DRUJ movements in healthy volunteers.

Methods

Electromagnetic measurement system

All experimental measurements were performed using an electromagnetic device (Liberty®, Polhemus, VT, USA). The system consists of a transmitter that produces an electromagnetic field and two three-dimensional electromagnetic sensors. This system had a root mean square accuracy of 0.76 mm for position and 0.15º for orientation when it was used within an optimal operational zone with transmitter-to-sensor separation within 106 cm, and there was no interference from the magnetic material[17]. Two sensors were used for motion measurement and attached to the radial aspect of the distal radius shaft (10 cm proximal to the radial styloid process) and the ulnar aspect of the ulnar head, respectively. The ulnar head translation with reference to the Y-axis of the sensor on the radial side was calculated on a personal computer using coordinated software (Fig. 1). The measurements and graphs were shown in real time with high sampling rates (60 Hz).

Assessment of EMS accuracy

Each sensor was attached to the blocks which imitated the radius and ulna of the DRUJ in forearm pronation (Fig 2a, 2b). One examiner moved the ulnar block to 1, 3, 5, and 10 mm on the dorsal and volar sides. Measurements were performed seven times on each side. The maximum and minimum values were excluded as outliers, and the mean value of the remaining five measurements was used for the analysis. Accuracy was assessed by calculating the error between the mean value of the measurements and the true value, standard deviation (SD), and Pearson’s correlation coefficient.

Assessment of EMS reproducibility

The bone model of the upper limb was fixed in 90° elbow flexion and the radius was in pronation (Fig. 3a). Two sensors were attached to the radial aspect of the distal radial shaft and ulnar aspect of the ulnar head, respectively (Fig. 3b). The examiner moved the ulnar head 10 mm from the dorsal to the volar side, mimicking the ballottement test, and measured the ulnar head translation relative to the radius. Measurements were performed seven times by five examiners, including the removal and attachment of sensors. The maximum and minimum values were excluded as outliers, and the mean value of the remaining five measurements was used for the analysis. Reproducibility was assessed to calculate the SD.

In vivo measurement

The protocol for in vivo measurements was reviewed and approved by our Institutional Review Board (No. B210009). Three experienced hand surgeons measured the dominant and non-dominant hands of 14 healthy volunteers (7 men and 7 women) with a mean age (and SD) of 33.4 ± 5.9 years. Volunteers were excluded if they had a history of wrist trauma or pain. Each subject was measured in the sitting position with the elbow flexed and the forearm 90° pronated. This limb measurement position, which mimics the piano key test, is highly reproducible in clinical practice. Each sensor was fixed to the side surface of the jigs that could grip the distal radial shaft (10 cm proximal to the radial styloid process) and the ulnar head from the dorsal and volar sides (Fig. 4a). The examiners grasped and fixed the distal end of the radius while moving the ulnar head from the dorsal to the volar side, mimicking the ballottement test, to measure the dorsovolar ulnar head translation with respect to the radius (Fig. 4b). The examiner moved the ulnar head 10 times in one measurement. The first and last two times were excluded, and the mean value of the remaining six times was taken as the result of one measurement. The examiner measured the dominant and non-dominant sides of the wrist seven times each. The maximum and minimum values were excluded as outliers, and the remaining five measurements were used for the analysis. The mean of the five measurements for each wrist was calculated as the result. The intraclass correlation coefficient (ICC) was calculated using the mean value of the measurements, and the intra- and inter-rater reliabilities were evaluated. The differences between the dominant and non-dominant sides and between men and women were assessed.

Statistical analysis

The results are expressed as mean ± SD. The Mann-Whitney U test was used for comparisons between the two groups. The level of significance was set at $p < 0.05$. Statistical analyses were performed using the Excel statistical software package (Ekuseru-Toukei 2015; Social Survey Research Information Co., Ltd., Tokyo, Japan) and SPSS Statistics (IBM, Tokyo, Japan) software.

Results

Assessment of EMS accuracy and reproducibility

Figure 5 shows the accuracy assessment results of the ulnar block movement during the measurements with a timeline. The measurements are shown in Table 1. When the ulnar block was moved 1, 3, 5, and 10 mm to the palmar side, the measurements were 1.03 ± 0.04, 2.90 ± 0.06, 4.99 ± 0.17, and 9.92 ± 0.17 mm, respectively. The error between the mean value of the measurements and the true value was less than 0.2 mm in all circumstances, and the SD was less than 0.1 mm. Pearson's correlation coefficient was 0.997 ($p = 0.89 \times 10^{-7}$).

Figure 6 shows the reproducibility assessment of the ulnar head movement during the measurements with a timeline. The measurements are shown in Table 2. When five examiners moved the ulnar head by 10 mm, the mean ulnar head translation was 10.08 ± 0.17 mm.

In vivo measurement

The ICC (1,5) indicating intra-rater reliability was 0.856, and the ICC (2,5) indicating inter-rater reliability was 0.868. The mean ulnar head translation of all measurements was 6.00 ± 1.16 mm (range, 4.27–9.10 mm), and that of the dominant and non-dominant sides were 5.93 ± 1.06 mm and 6.05 ± 1.25 mm, respectively (Fig. 7). There were no significant differences between the dominant and non-dominant sides. The mean ulnar head translation of men and women were 5.78 ± 1.18 mm and 6.22 ± 1.10 mm, respectively (Fig. 8). The mean of the difference between the dominant and non-dominant sides was -0.12 ± 0.40 mm (-0.90–0.67 mm), and that of men and women were -0.06 ± 0.21 mm and -0.17 ± 0.52 mm, respectively (Fig. 9). There was no significant difference between men and women regarding the amount of ulnar head movement and the difference between the dominant and non-dominant sides.

Discussion

Several methods using imaging data have been reported to objectively evaluate DRUJ instability, including plain radiography, computerized tomography (CT), and ultrasound examination[18-31]. Nakamura et al. reported that DRUJ subluxation and dislocation were indicated when the difference in the radioulnar distance between the affected and non-affected wrists was 6 mm or more on a normal lateral radiograph[18]. Additionally, on a posteroanterior radiograph, a widened gap between the distal radius and the ulna with respect to the unaffected side is a strong indicator of dorsal ulnar subluxation/dislocation, while increased overlap indicates volar ulnar subluxation/dislocation[19,20]. However, a true lateral view of the DRUJ was difficult to take, and as little as 10° of supination or pronation made radiographic diagnoses inaccurate[19-21].

Bilateral CT evaluation of the DRUJs is useful for detecting differences in anatomical details and DRUJ congruency between normal and injured wrists[22,23]. There are various methods of quantifying the instability on axial CT images, such as the radioulnar line (or Mino's) method, the radioulnar ratio method, the subluxation ratio method, the epicenter method, and the congruency method[19, 24-28]. The radioulnar line method and the congruency method showed high false-positive rates[29], while the epicenter method was the most specific and reliable among them[28, 29]. However, there was no clear statistical correlation between the stress test and CT parameters for DRUJ instability after distal radius fracture[30]. In addition, since both plain radiography and CT are static evaluations, the instability of DRUJ could be underestimated.

Recently, musculoskeletal evaluation using ultrasonography has become widespread. The potential advantages of ultrasound are its noninvasiveness, low cost, lack of ionizing radiation risk, and dynamic and real-time evaluation. Hess et al. reported a sonographic method of quantifying DRUJ instability by measuring volar ulnar head translation relative to the distal radius with the forearm pronated, and distinguished a normal from an unstable DRUJ[31]. They showed that the average volar translation and differences between both wrists with normal DRUJ were 2.5 mm and 0.65 mm, and those of unstable DRUJ were 5.8 mm and 2.8 mm[31]. However, they only assessed volar side instability, and ultrasound devices remain dependent on the operator and experience.

The reliability of EMS has been reported in the quantification of the Lachman test and pivot-shift test, which evaluate knee laxity after ACL injuries[9-16]. The measurements could be useful for understanding the pathophysiology of ACL injury pattern[9-16]. In this study, a new quantitative evaluation system for DRUJ movement using an EMS was developed. As a result of the accuracy assessment of the EMS, the error between the mean of the measurements and the true value was < 0.2 mm, SD was < 0.1 mm and Pearson's correlation coefficient was 0.997, indicating high accuracy. Similarly, the reproducibility evaluation of the EMS showed that SD was < 0.17 mm, indicating high reproducibility. Furthermore, in vivo measurements of the ICC demonstrated almost perfect intra- and inter-rater reliabilities[32], with an ICC (1,5) of 0.856 and an ICC (2,5) of 0.868. These results suggest that the EMS could be a clinically useful measurement method for quantifying DRUJ movement.

A previous cadaveric study investigated DRUJ movement during the ballottement test with a non-holding technique using a magnetic sensor system, and reported that the average movement before TFCC sectioning was 10.8 mm[33]. Ultrasound measurements reported a volar ulnar head translation of 2.5 mm in the pronated position[31]. In the in vivo measurements of this study, the mean dorsovolar ulnar head translation in healthy volunteers was approximately 6.0 mm, which was lower than that in the cadaveric report and higher than that in the ultrasound study. These results seem to be reasonable in comparison with the cadaveric study, considering that the dynamic stability through muscle contraction was affected and the forearm was examined in the pronated position. In addition, dorsal instability has not been adequately investigated in ultrasonographic studies; therefore, dorsovolar ulnar head translation may be underestimated. In the comparison between the dominant and non-dominant sides, ulnar head translation was slightly greater on the non-dominant side; however, there were individual differences, and no significant differences were found. Although the translation distance of females tended to be higher than that of males, there was no significant difference between males and females in each parameter, which was similar to a previous report using CT evaluation[34]. DRUJ instability varies greatly among individuals and is difficult to assess, especially in patients with joint laxity. This study also had a large normal range of 4.28–9.10 mm. Therefore, it is important to compare the difference between the healthy side and the affected side[28,29,34]. In the cadaveric study mentioned above, DRUJ instability increased by 2.3 mm after TFCC sectioning[33]. The ultrasonographic study reported that the average difference between both wrists with normal DRUJ was 0.65 mm, while with unstable DRUJ, it was 2.8 mm[31]. Another study on CT assessment under stress in the neutral position reported that a contralateral difference of 2–3 mm suggested instability[34]. In this study, the average difference between the dominant and non-dominant sides was 0.11 mm (0.01 to 0.90 mm) in healthy volunteers. These results suggest that a difference of < 1 mm between both wrists might be considered a stable DRUJ.

The advantage of the EMS is that dynamic changes in the DRUJ can be assessed objectively and in real time without any invasion or exposure[9-16]. TFCC injury is the main cause of DRUJ instability, but some cases are difficult to diagnose even with MRI or arthrography. Thus, objective measurement using EMS could help in the diagnosis and understanding of the pathology. Furthermore, EMS can be used for postoperative evaluation. These benefits demonstrate the potential of EMS as a clinically useful test.

This study has several limitations. First, the effect of the skin motion was not evaluated. Therefore, it would be preferable to assess this in a cadaveric study. However, the influence of skin motion was minimized by devising a measurement device to firmly grip the DRUJ. The soft tissue around the DRUJ is thin; thus, the influence of skin motion on the results should be minimal. In addition, our in vivo measurements showed that the ICC (1,5) and ICC (2,5) were 0.856 and 0.868, respectively, and the ulnar head translation was also reasonable compared to that of the cadaveric study using the magnetic sensor system[33]. Second, a comparison with other imaging tests was not performed. Third, the sample size was small; however, we successfully confirmed the effectiveness of the measurement system and the values from healthy subjects in this study. We would like to further increase the sample size and compare the results with those of the patient group in the future.

Conclusions

In this study, a new measurement method using an EMS was used to evaluate the movement of the DRUJ with high accuracy, reproducibility, and intra- and inter-rater reliabilities. In this measurement method, the dorsovolar ulnar head translation was approximately 6.00 mm, and the difference between the dominant and non-dominant sides was < 1.0 mm in healthy subjects. EMS can evaluate dynamic changes in the DRUJ objectively, non-invasively, and in real-time, suggesting that it could be a clinically-applicable measurement method.

Declarations

Ethics approval and consent to participate

Our Institutional Review Board (IRB) At Kobe University provided the approval for our study and the approval informations are follows. (Permission Number: B210009). All procedures were performed under the approval and guidance of our IRB.

Consent for publication

Written consents for publication were obtained from all study participants.

Availability of data and materials:

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

Funding information is not applicable.

Authors' contributions:

SM, YM, AI and KN contributed to the conception and design of the study. SM, TKU, KY, TY and IS performed the experiments and collected the data. Data and statistical analysis were done by SM, YM and AI. Manuscript preparation was done by SM, YM and AI. Supervising was done by RK. All authors read and approved the final manuscript.

Acknowledgements

The authors would like to thank Editage (www.editage.com) for English language editing.

Abbreviations

ACL Anterior cruciate ligament

CT Computed tomography

DRUJ Distal radioulnar joint

EMS Electromagnetic sensor system

ICC Inter-rater/intraclass correlation coefficient

SD Standard deviation

TFCC Triangular fibrocartilage complex

References

1. Linscheid RL. Biomechanics of the distal radioulnar joint. Clin Orthop. 1992;275:46–55.
2. Haugstvedt JR, Langer MF, Berger RA. Distal radioulnar joint: functional anatomy, including pathomechanics. J Hand Surg Eur Vol. 2017;42(4):338–45. doi: 10.1177/1753193417693170.
3. Gofton WT, Gordon KD, Dunning CE, Johnson JA, King GJ. Soft tissue stabilizers of the distal radioulnar joint: an in vitro kinematic study. J Hand Surg Am. 2004;29(3):423–31.
4. Skahen JR III, Palmer AK, Werner FW, Fortino MD. The interosseous membrane of the forearm: anatomy and function. J Hand Surg Am. 1997;22(6):981–5.
5. Adams JE. Forearm Instability: Anatomy, Biomechanics, and Treatment Options. J Hand Surg Am. 2017;42(1):47–52. doi: 10.1016/j.jhsa.2016.10.017.
6. Palmer AK, Werner FW. Biomechanics of the distal radioulnar joint. Clin Orthop. 1984;187:26–35.
7. Andersson JK, Axelsson P, Str€omberg J, Karlsson J, Friden J. Patients with triangular fibrocartilage complex injuries and distal radioulnar joint instability have reduced rotational torque in the forearm. J Hand Surg Eur. 2016;41(7):732–8.
8. Moriya T, Aoki M, Iba K, Ozasa Y, Wada T, Yamashita T. Effect of triangular ligament tears on distal radioulnar joint instability and evaluation of three clinical tests: a biomechanical study. J Hand Surg Eur. 2009;34:219–23.
9. Hoshino Y, Kuroda R, Nagamune K, Yagi M, Mizuno K, Yamaguchi M, et al. In vivo measurement of the pivot-shift test in the anterior cruciate ligament-deficient knee using an electromagnetic device. Am J Sports Med. 2007;35:1098–104.
10. Araki D, Kuroda R, Kubo S, Nagamune K, Hoshino Y, Nishimoto K, et al. The use of an electromagnetic measurement system for anterior tibial displacement during the Lachman test. Arthroscopy. 2011;27:792–802.
11. Hoshino Y, Araujo P, Irrgang JJ, Fu FH, Musahl V. An image analysis method to quantify the lateral pivot shift test. Knee Surg Sports Traumatol Arthrosc. 2012;20(4):703–7.
12. Araujo PH, Ahlden M, Hoshino Y, Muller B, Moloney G, Fu FH, et al. Comparison of three non-invasive quantitative measurement systems for the pivot shift test. Knee Surg Sports Traumatol Arthrosc. 2012;20:692–7.
13. Araki D, Kuroda R, Matsushita T, Matsumoto T, Kubo S, Nagamune K, et al. Biomechanical analysis of the knee with partial anterior cruciate ligament disruption: quantitative evaluation using an electromagnetic measurement system. Arthroscopy. 2013;29:1053–62.
14. Hoshino Y, Araujo P, Ahldén M, Samuelsson K, Muller B, Hofbauer M, et al. Quantitative evaluation of the pivot shift by image analysis using the iPad. Knee Surg Sports Traumatol Arthrosc. 2013;21:975–80.
15. Nagai K, Hoshino Y, Nishizawa Y, Araki D, Matsushita T, Matsumoto T, et al. Quantitative comparison of the pivot shift test results before and after anterior cruciate ligament reconstruction by using the three-dimensional electromagnetic measurement system. Knee Surg Sports Traumatol Arthrosc. 2015;23:2876–81.

16. Tanaka T, Hoshino Y, Miyaji N, Ibaragi K, Nishida K, Nishizawa Y, et al. The diagnostic reliability of the quantitative pivot-shift evaluation using an electromagnetic measurement system for anterior cruciate ligament deficiency was superior to those of the accelerometer and iPad image analysis. Knee Surg Sports Traumatol Arthrosc. 2018;26(9):2835–40. doi: 10.1007/s00167-017-4734-0. Epub 2017 Oct 14.
17. Milne AD, Chess DG, Johnson JA, King GJW. Accuracy of an electromagnetic tracking device: a study of the optimal operating range and metal interference. J Biomech. 1996;29:791–3.
18. Nakamura R, Horii E, Imaeda T, Tsunoda K, Nakao E. Distal radioulnar joint subluxation and dislocation diagnosed by standard roentgenography. Skeletal Radiol. 1995;24:91–4.
19. Mino DE, Palmer AK, Levinsohn EM. The role of radiography and computed tomography in the diagnosis of subluxation and dislocation of the distal radioulnar joint. J Hand Surg. 1983;8:23–31.
20. Mino DE, Palmer AK, Levinsohn EM. Radiography and computerized tomography in the diagnosis of incongruity of the distal radio-ulnar joint. A prospective study. J Bone Joint Surg Am 1985;67:247–52.
21. Tsai PC, Paksima N. The distal radioulnar joint. Bull NYU Hosp Jt Dis. 2009;67(1):90–6.
22. Duryea DM, Payatakes AH, Mosher TJ. Subtle radiographic findings of acute, isolated distal radioulnar joint dislocation. Skeletal Radiol. 2016;45(9):1243–7. doi: 10.1007/s00256-016-2411-x.
23. Amrami KK, Moran SL, Berger RA, Ehman EC, Felmlee JP. Imaging the distal radioulnar joint. Hand Clin. 2010;26(4):467–75. doi: 10.1016/j.hcl.2010.07.001.
24. Squires JH, England E, Mehta K, Wissman RD. The role of imaging in diagnosing diseases of the distal radioulnar joint, triangular fibrocartilage complex, and distal ulna. AJR Am J Roentgenol. 2014;203(1):146–53. doi: 10.2214/AJR.13.11573.
25. Gulati A, Wadhwa V, Ashikyan O, Cerezal L, Chhabra A. Current perspectives in conventional and advanced imaging of the distal radioulnar joint dysfunction: review for the musculoskeletal radiologist. Skeletal Radiol. 2019;48(3):331–48. doi: 10.1007/s00256-018-3042-1. Epub 2018 Sep 1.
26. Lo IKY, MacDermid JC, Bennett JD, Bogoch E, King GJW. The radioulnar ratio: a new method of quantifying distal radioulnar joint subluxation. J Hand Surg Am. 2001;26(2):236–43. doi: 10.1053/jhsu.2001.22908.
27. Wechsler RJ, Wehbe MA, Rifkin MD, Edeiken J, Branch HM. Computed tomography diagnosis of distal radioulnar subluxation. Skeletal Radiol. 1987;16(1):1–5. doi: 10.1007/BF00349919.
28. Wijffels M, Stomp W, Krijnen P, Reijnierse M, Schipper I. Computed tomography for the detection of distal radioulnar joint instability: normal variation and reliability of four CT scoring systems in 46 patients. Skeletal Radiol. 2016;45(11):1487–93. doi: 10.1007/s00256-016-2455-y.
29. Nakamura R, Horii E, Imaeda T, Nakao E. Criteria for diagnosing distal radioulnar joint subluxation by computed tomography. Skeletal Radiol. 1996;25:649–53.
30. Kim JP, Park MJ. Assessment of distal radioulnar joint instability after distal radius fracture: comparison of computed tomography and clinical examination results. J Hand Surg Am. 2008;33(9):1486–92. doi: 10.1016/j.jhsa.2008.05.017.

31. Hess F, Farshad M, Sutter R, Nagy L, Schweizer A. A novel technique for detecting instability of the distal radioulnar joint in complete triangular fibrocartilage complex lesions. J Wrist Surg. 2012;1(2):153–8. doi: 10.1055/s-0032-1312046.
32. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977;33(1):159–74.
33. Onishi T, Omokawa S, Iida A, Nakanishi Y, Kira T, Moritomo H, et al. Biomechanical study of distal radioulnar joint ballottement test. J Orthop Res. 2017;35:1123–7
34. Pirela-Cruz MA, Goll SR, Klug M, Windler D. Stress computed tomography analysis of the distal radioulnar joint: a diagnostic tool for determining translational motion. J Hand Surg Am. 1991;16:75–82

Tables

Table 1. The measurements of ulnar block movement for assessment of accuracy

		1	2	3	4	5	Average (mm)	SD(mm)
Dorsal side (mm)	10	9.98	9.7	9.98	9.78	10.19	9.92	0.17
	5	5.12	4.72	4.94	5.21	4.99	4.99	0.17
	3	2.95	2.79	2.89	2.91	2.99	2.9	0.06
	1	0.97	1.08	1.07	1.01	1.04	1.03	0.04
Palmar side (mm)	-1	-1.09	-1.11	-1.07	-0.97	-1.12	-1.07	0.06
	-3	-3.26	-3.14	-3.24	-3.11	-3.14	-3.18	0.06
	-5	-5.03	-5.08	-5.18	-5.21	-5.16	-5.13	0.07
	-10	-10.13	-10.29	-10.16	-10.1	-10.03	-10.14	0.09

	Examiner					Average (mm)	SD (mm)
	A	B	C	D	E		
Ulnar head translation (10mm)	10.16	10.2	9.99	10.01	10.03	10.08	0.17

Table 2. The measurements of ulnar head movement for assessment of reproducibility

Figures

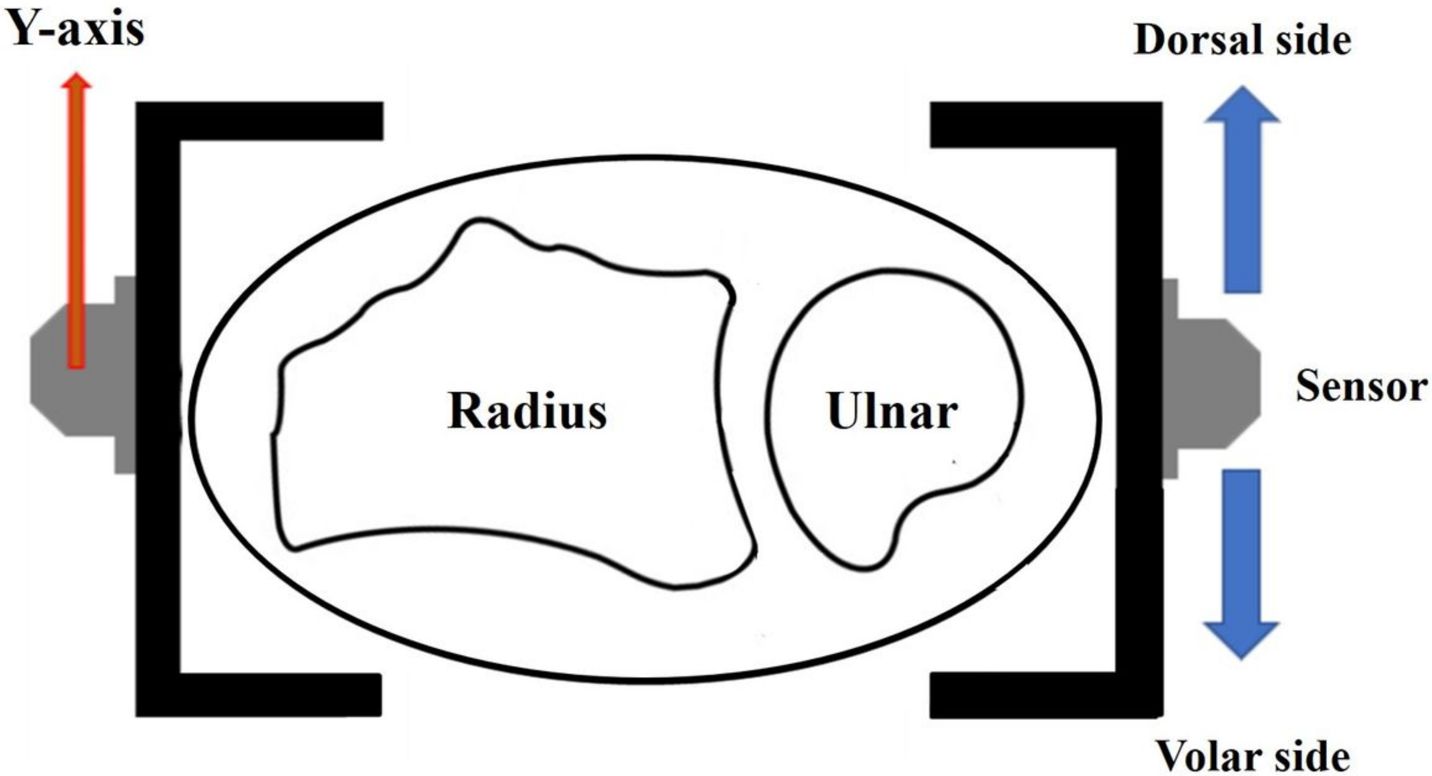

Figure 1

Electromagnetic measurement system

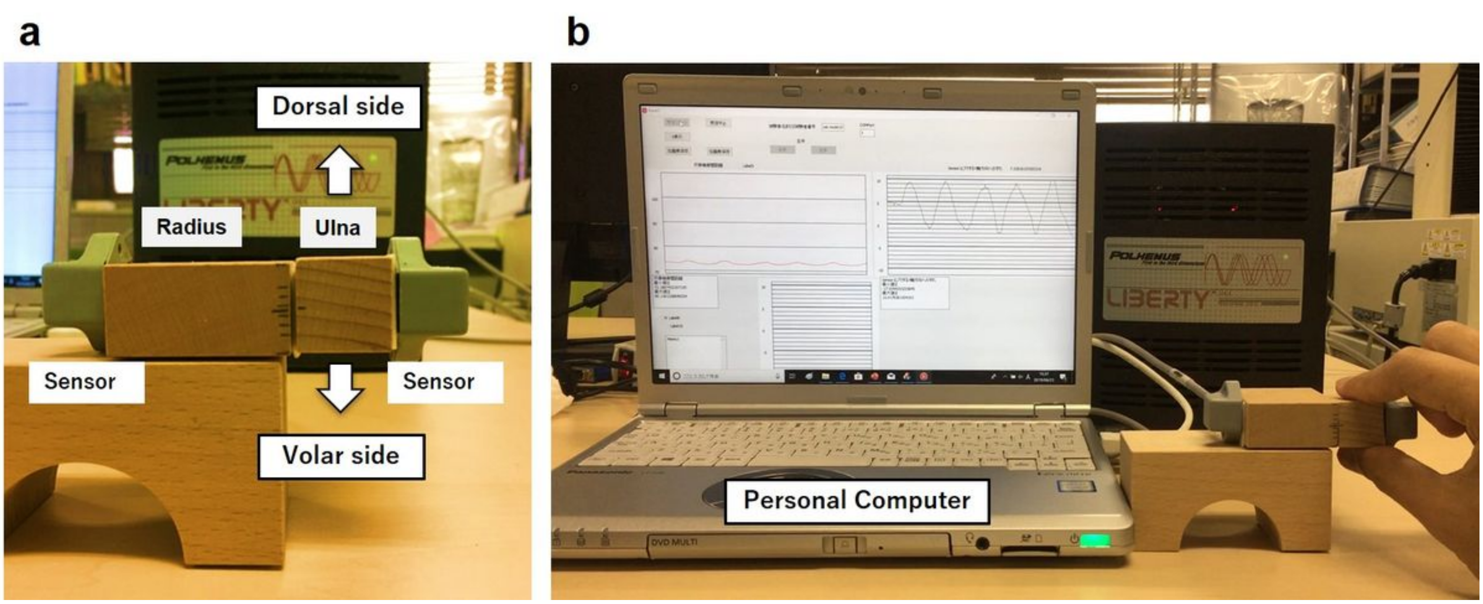

Figure 2

a. Each electromagnetic sensor was attached to the blocks which imitated the radius and ulna of DRUJ in forearm pronation. The ulnar block was moved to volar side and dorsal side. b. The measurements can be monitored in real time on a screen of personal computer.

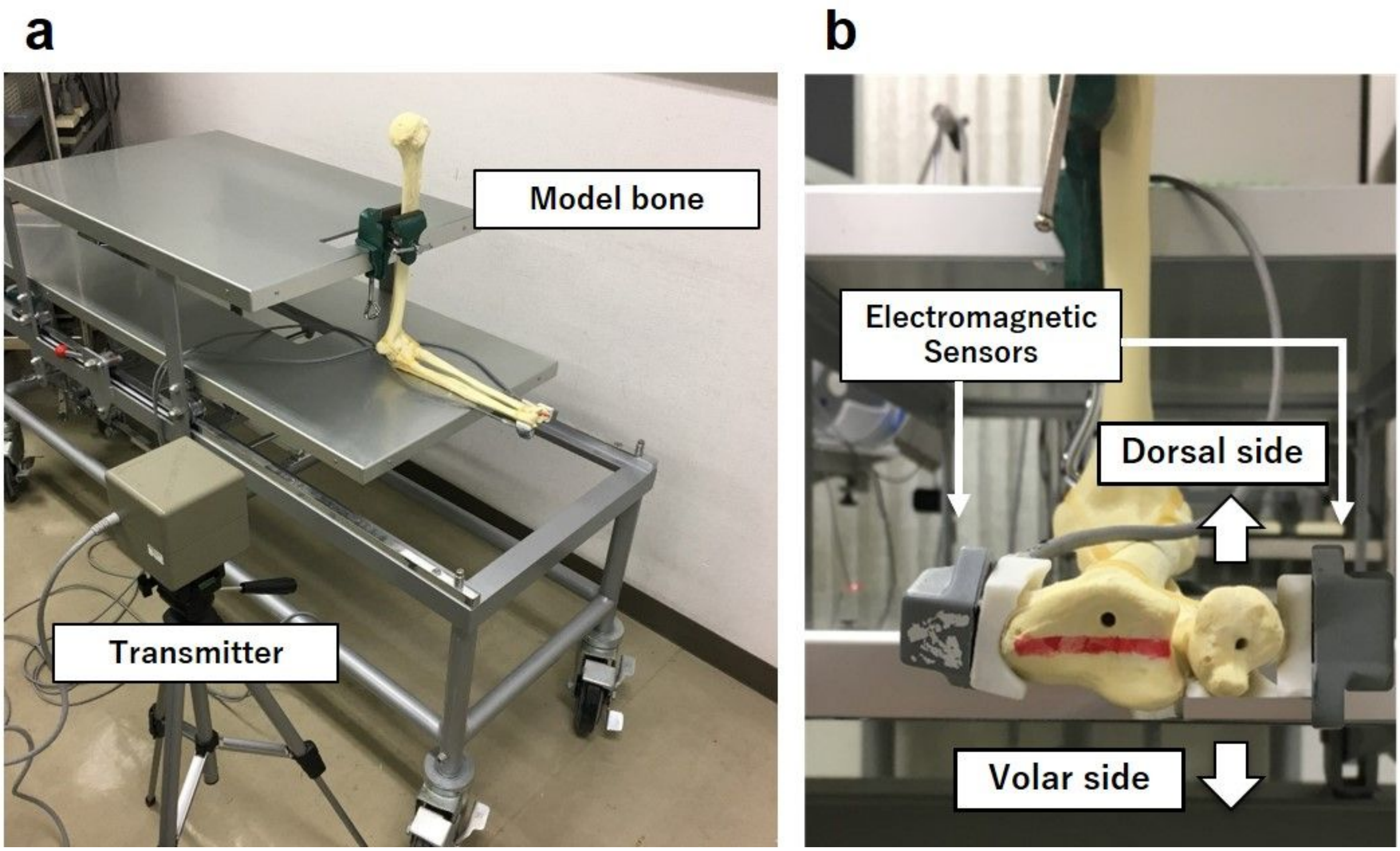

Figure 3

a. The bone model of the upper limb was fixed in 90° elbow flexion and the radius was in pronation. b. Two sensors were attached to the radius and the ulnar styloid process.

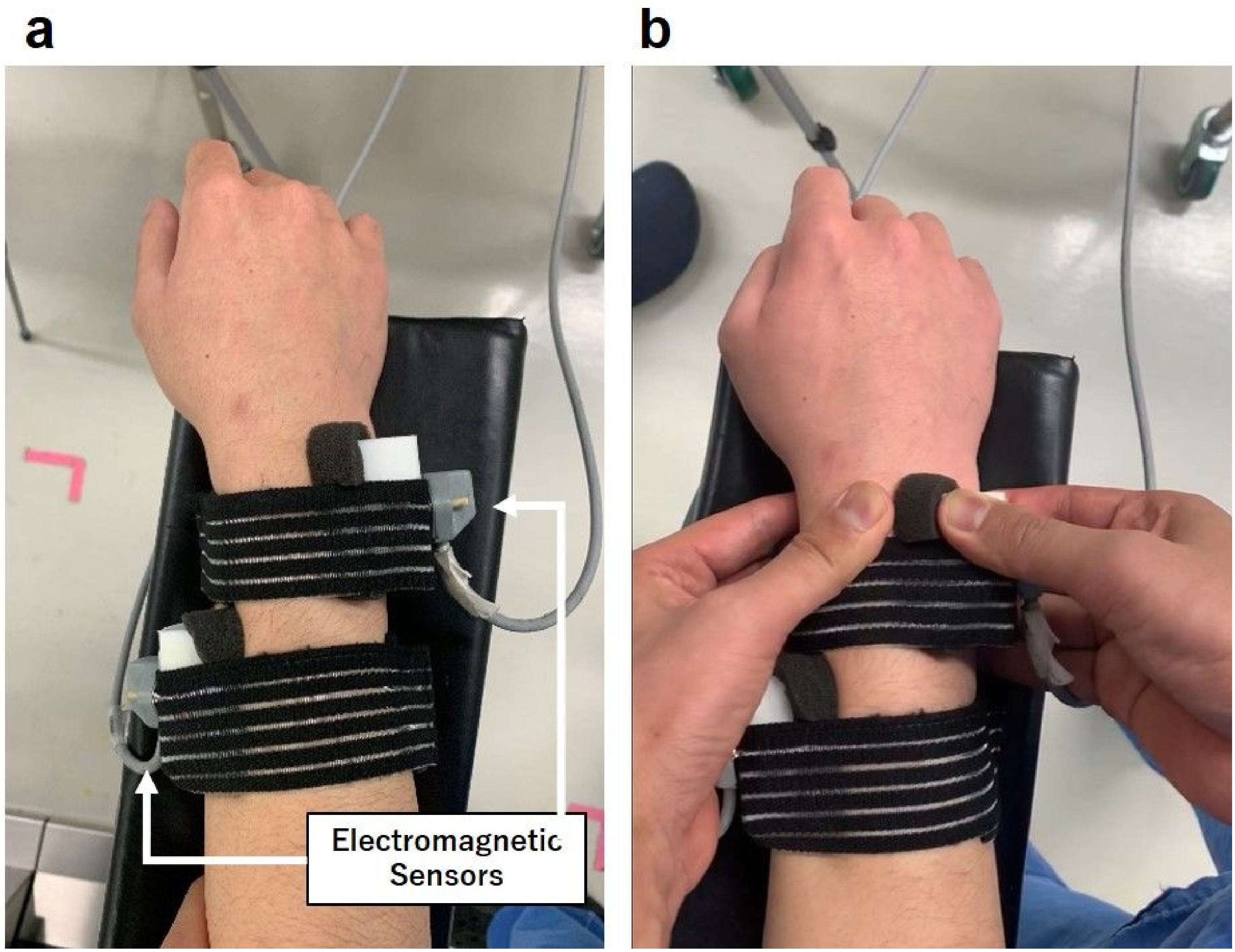

Figure 4

a. Measurements were taken with the elbow flexed to 90° and the forearm in pronation. Each sensor was fixed to the side surface of jigs that could grip the distal radial shaft and the ulnar head. b. The examiners grasped and fixed the distal end of the radius and moved the ulnar head from the dorsal to the palm side to measure the dorsovolar ulnar head translation with respect to the radius.

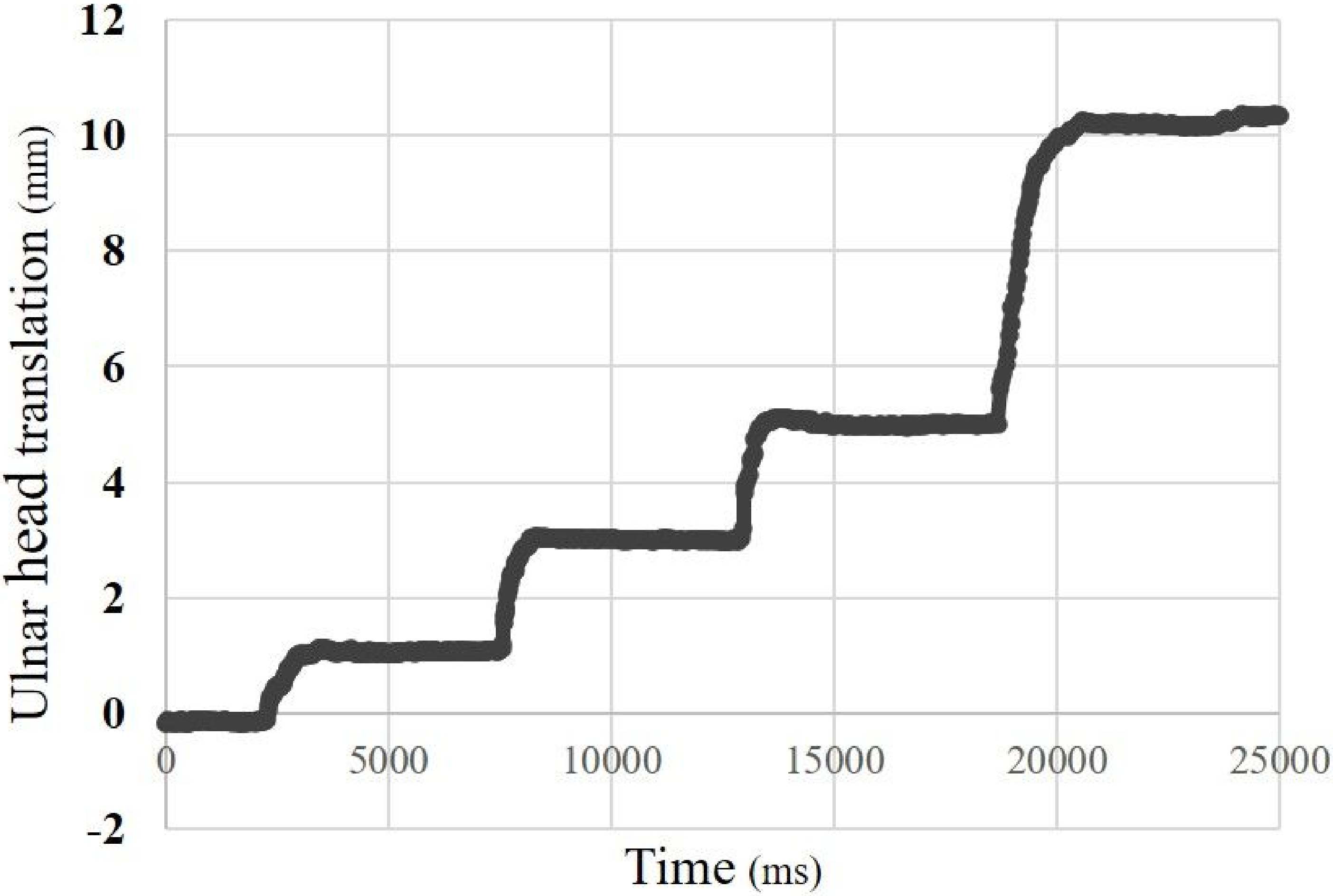

Figure 5

The ulnar block movement during measurement with a timeline

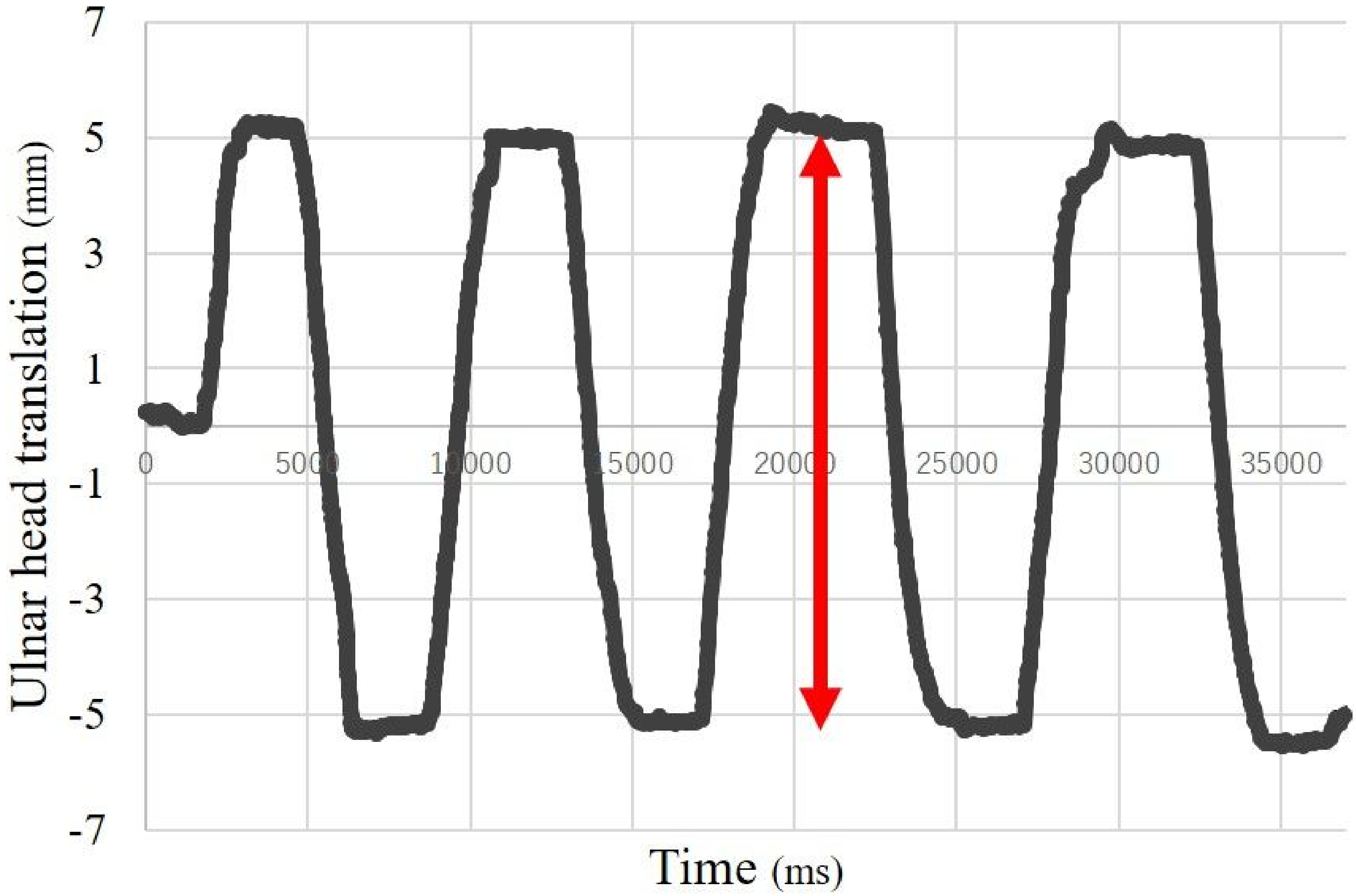

Figure 6

The ulnar head movement during measurement with a timeline

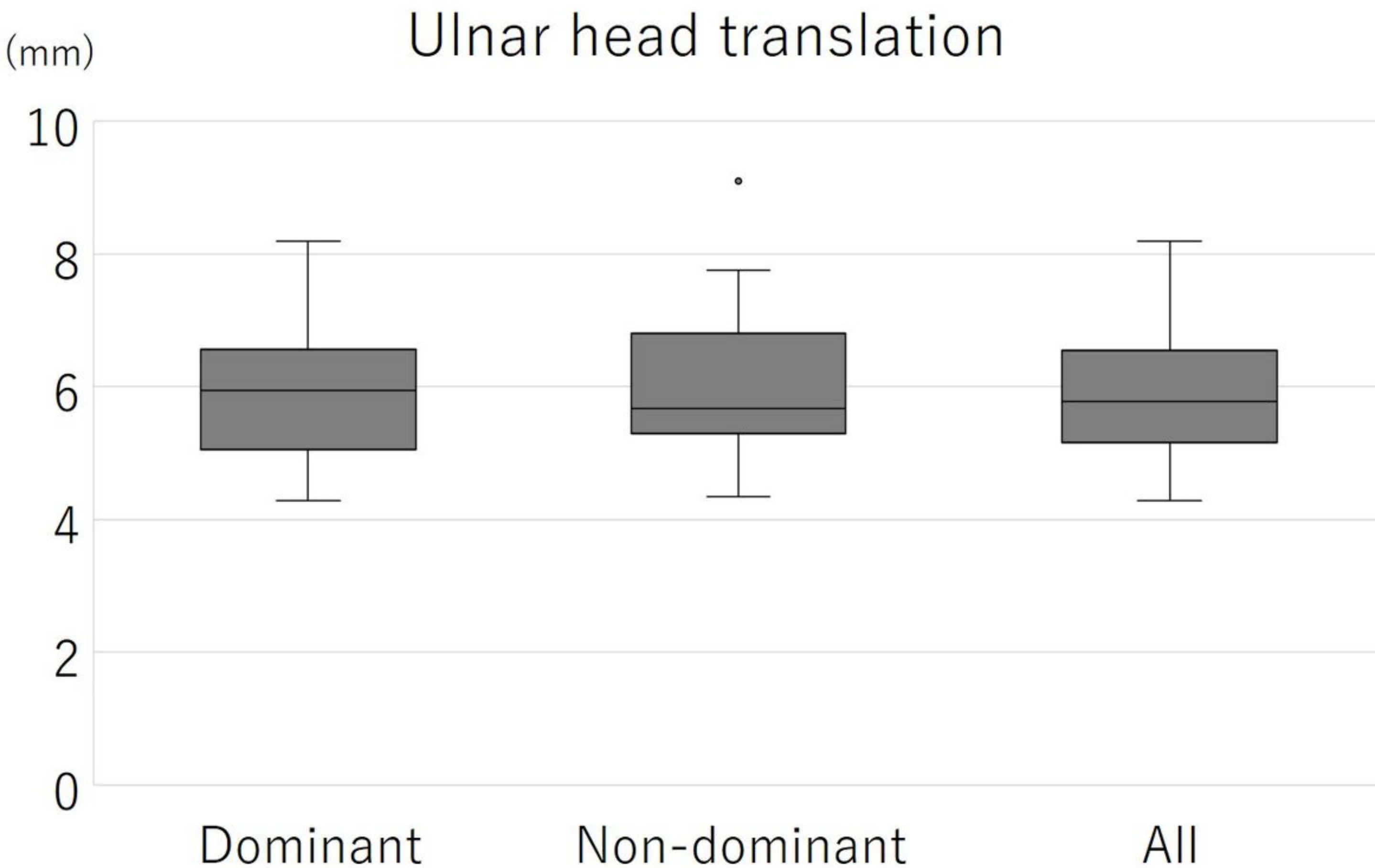

Figure 7

The ulnar head translation on dominant and non-dominant sides

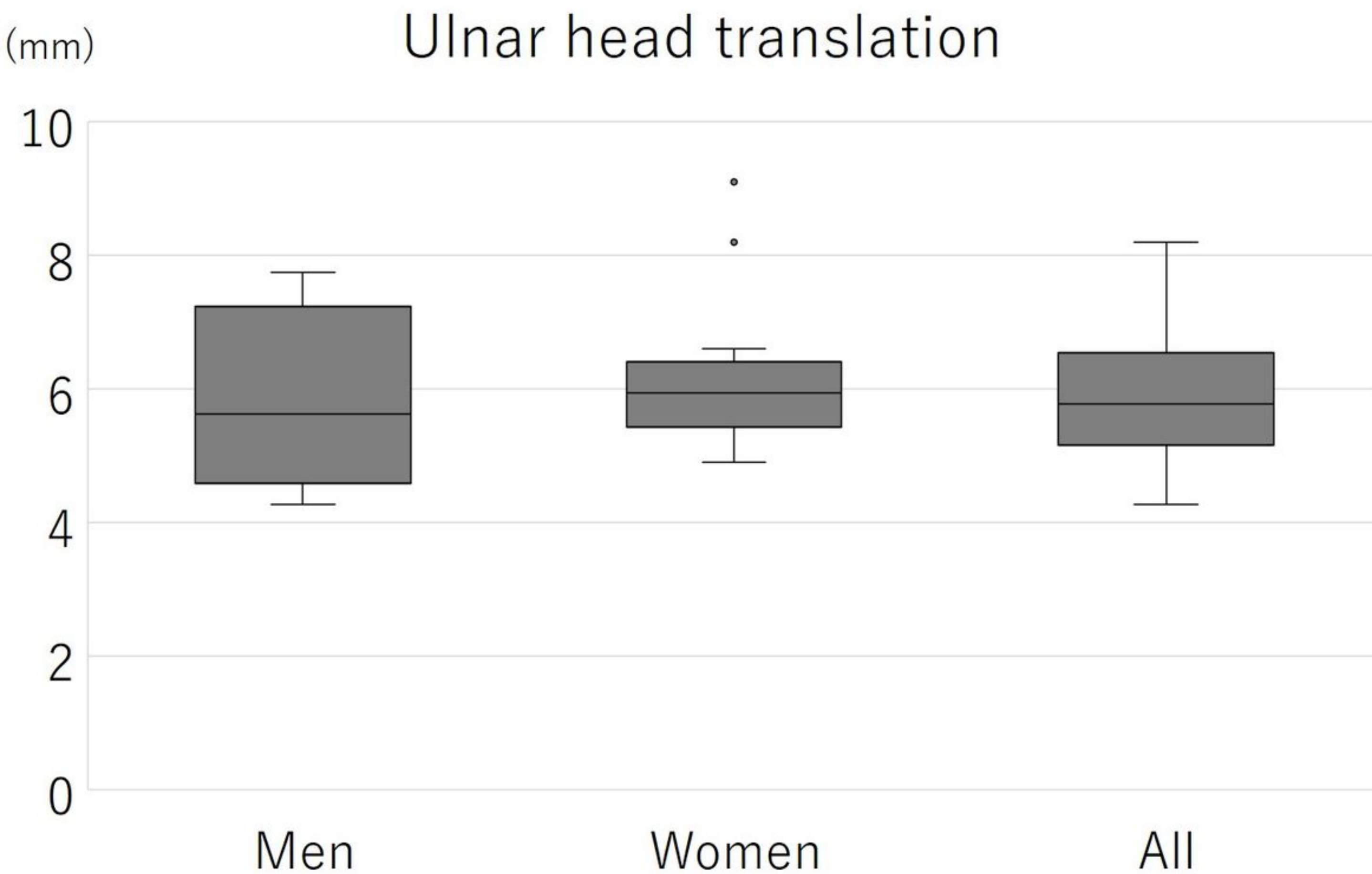

Figure 8

The ulnar head translation in men and women

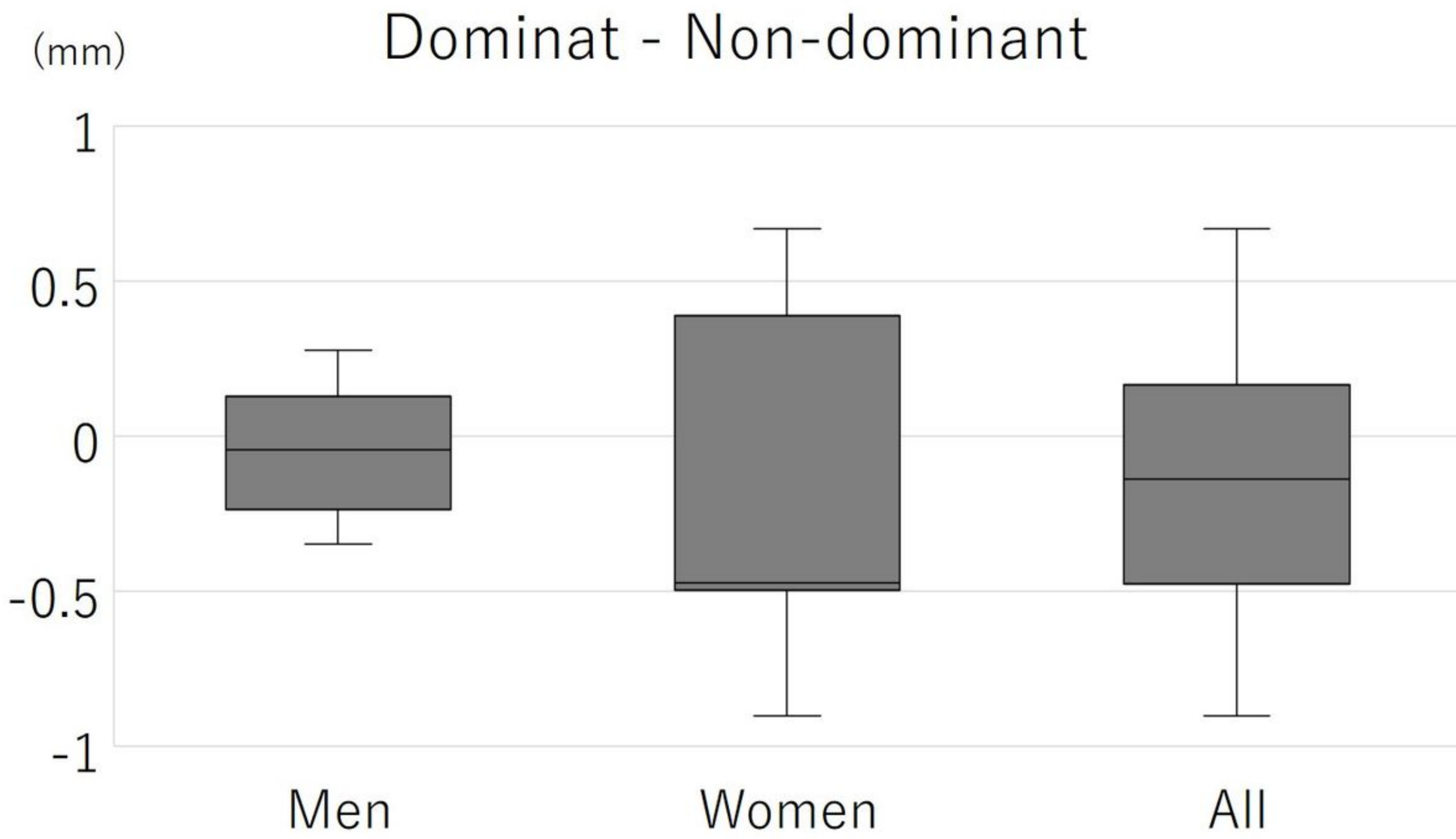

Figure 9

The difference in ulnar translation between the dominant and non-dominant sides in men and women

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- coveringletter.doc