RESEARCH ARTICLE

Accuracy and reliability of tridimensional electromagnetic sensor system for elbow ROM measurement

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Abstract

Background: While the precise measurement of the range of motion (ROM) of the elbow joint is important for clinical assessment and rehabilitation, problems include low accuracy and reproducibility in goniometer measurements due to the influence of soft tissue. The purpose of this study was to validate elbow joint motion analysis using a three-dimensional electromagnetic sensor system (EMS).

Methods: The accuracy and reproducibility of the EMS system were evaluated at four angles (0°, 45°, 90°, and 135°) using a model bone of the humerus and forearm. In addition, the maximum extension and maximum flexion of six elbows of six healthy volunteers were assessed by radiographic and EMS measurements. Accuracy was assessed by calculating the mean value of the measurement angle, standard deviation, Pearson's correlation coefficient, and the Bland–Altman method. Reproducibility was assessed by calculating the intra-rater and inter-rater reliabilities using intraclass correlation coefficients.

Results: In the model bone evaluation, the mean angles of the EMS measurement were 1.2° ± 2.0°, 45.4° ± 2.1°, 91.7° ± 2.4°, and 134.6° ± 2.7° at 0°, 45°, 90°, and 135°, respectively. In the in vivo evaluation, the elbow angles at the maximum extension with the EMS and radiographic angles were 4.7° ± 3.0° and 2.7° ± 2.0°, respectively, and the angles at maximum flexion were 131.8° ± 13.0° and 130.8° ± 4.5°, respectively. There were statistically significant correlations between the EMS and radiographic measurements; the Bland–Altman plots indicated that the two methods were almost in agreement for both extension and flexion.

Conclusions: This method of measuring ROM of the elbow joint using EMS showed high accuracy, reliability, and reproducibility. The current results demonstrated the possibility of using the electromagnetic system to provide an accurate evaluation of the elbow joint in clinical settings.

Keywords: Elbow joint, Electromagnetic sensor system, Range of motion

Background

Precise measurement of the range of motion (ROM) of the joint is essential for clinical assessment in outpatient clinics and operating rooms. The universal goniometer (UG) has been widely used to measure ROM of the joint in the clinical setting by many medical practitioners, such as orthopedic surgeons and physical therapists, and is considered the gold standard [1, 2]. Although the UG is a simple measuring tool, there are problems of low accuracy and reproducibility due to the influence of soft tissue [3, 4]. Several studies have reported that UG has fair intra-examiner reliability but poor inter-examiner...
reliability [1, 5]. Radiographic measurement for ROM evaluation has been proposed as an alternative to UG. This method has shown a higher level of accuracy; however, it requires a radiological imaging system, time, cost, and even radiation exposure for the patient [6].

A quantitative assessment method of knee motion with high reproducibility using a three-dimensional electromagnetic sensor system (EMS) has been recently reported [7–13]. A three-dimensional motion tracking system using electromagnetic sensors has a high accuracy and a high sampling rate when capturing the relative movement between the objects and has been applied for joint motion assessments with the benefit of non-invasiveness to the human body. Although this highly accurate EMS has been frequently applied to the evaluation of knee joint function, there have been no reports of its application to the elbow joint. The elbow joint is a trochoginglymoid joint that articulates the distal humerus with the proximal radius and ulna, allowing wide ROM in flexion and extension movements [6]. We hypothesized that EMS could be used to measure the ROM of the elbow joint with high accuracy and reliability. Therefore, the purpose of this study was to validate a new application of elbow joint motion analysis using a three-dimensional EMS.

Methods
Experimental setup
The extension and flexion angles of the elbow joints were measured using an electromagnetic device (Liberty®, Polhemus, VT, USA). The system consists of a transmitter that produces an electromagnetic field and three-dimensional electromagnetic sensors. This system had a root-mean-square accuracy of 0.76 mm for position and 0.15° 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 magnetic material [14].

Two electromagnetic sensors were fixed to the humerus diaphysis and ulna diaphysis. The third electromagnetic sensor was used to register the three-dimensional positions of the five bone-based landmarks (pg: greater tubercle of humerus, pm: medial epicondyle of humerus, pl: lateral epicondyle of humerus, pr: styloid process of the radius, pu: styloid process of ulna, pm2: midpoint of pm and pl, and pm2: midpoint of pm and pu). The elbow joint flexion angle \( \phi \) was defined as \( \cos^{-1} (u_y \cdot f_y) \)

Assessment of EMS accuracy and reproducibility
The accuracy and reproducibility of the system were evaluated using a model bone of the humerus and forearm (Fig. 2a). The two sensors were fixed to the humerus
In vivo assessment of EMS

The protocol for in vivo measurements was reviewed and approved by our institutional review board (No. B210009). The study included six healthy men who volunteered to participate. The mean age was 33.4 ± 5.9 years (range, 24–41 years). The exclusion criteria included elbow pain, current elbow disorder, or a history of elbow surgery. The measurement brace with one sensor fixed was worn on the upper arm and forearm, as shown in Fig. 3. The third electromagnetic sensor was used to register the five landmarks in the same manner as the model bone. All participants were right-handed, and only the dominant side was evaluated. The participants were measured in a sitting position and performed active flexion and extension of the elbow joint with anterior elevation of the shoulder joint and forearm in maximal supination. Lateral radiographic images of the elbow joint were captured with the C-arm fluoroscopy system, BV Pulsera (Philips Medical Systems, The Netherlands) in the maximum flexion and extension positions for approximately 3 s. Radiographic images were considered a more accurate method for ROM measurement because of the advantage of being unaffected by the morphological features of the patient [6, 14, 16]. To obtain a complete lateral view of the elbow, the humeral capitellum and trochlea were photographed so that they appeared as concentric as possible [17]. Each participant was radiographed in maximal flexion and extension positions twice. In addition, once the brace and device were removed, this series of examinations was repeated twice. The total number of EMS and radiological measurements were 36 measurements in the flexion and extension positions of the elbow joint. To evaluate the accuracy and precision of the EMS measurement, the difference between the EMS and gold standard radiological measurements for each pair of 36 measurements was analyzed using the Bland–Altman method [18–20]. Reproducibility was assessed to calculate the intra-rater reliability and inter-rater reliability using ICCs.
Statistical analysis

Statistical analyses were performed using SPSS software (PASW, version 18.0, SPSS Inc., Chicago, USA), and the data were expressed as the mean ± standard deviation. Statistical significance was set at \( p < 0.05 \). To evaluate the accuracy of EMS measurements and radiological measurements, the Bland–Altman method was used in this study. The Bland–Altman method is commonly used in method comparison studies, in which measurements are taken by two methods at the same time, and the differences between these measurements are examined [21].

Results

Assessment of EMS accuracy and reproducibility

The timeline of the measurement angles with the EMS for one participant is shown in Fig. 4. The measurement results are presented in Table 1. The mean flexion angles ± SD with EMS in the model bone elbow joint were \( 1.2^\circ ± 2.0^\circ, 45.4^\circ ± 2.1^\circ, 91.7^\circ ± 2.4^\circ, \) and \( 134.6^\circ ± 2.7^\circ \) in 0°, 45°, 90°, and 135° degrees of flexion with a goniometer, respectively. The error between the mean measurement angle with the EMS of the measurements and the actual measurement angle was less than 1.7° in all circumstances, and the SD was less than 2.7°. The Pearson’s correlation coefficient was 0.999 (\( p < 0.0001 \)).

The intra-rater and inter-rater ICCs for EMS measurements are shown in Table 2. The ICC (1,3) indicating intra-rater reliability was 1.000, and the ICC (2,3) indicating inter-rater reliability was 1.000.

In vivo assessment of EMS

The mean angles of maximum extension and flexion measured with EMS were \( 4.7^\circ ± 3.0^\circ \) and \( 131.8^\circ ± 13.0^\circ \), whereas the mean angles of the maximum extension and flexion measured with radiographic assessment were \( 2.7^\circ ± 2.0^\circ \) and \( 130.8^\circ ± 4.5^\circ \), respectively.
The measurement results are presented in Table 3. The mean angles of radiographic and EMS measurements in flexion and extension positions of the elbow joints and the Pearson correlation coefficient are shown. There were significant correlations between radiographic and EMS measurements in both the flexion and extension positions.

The Bland–Altman analysis between the radiographic and EMS measurements in both flexion and extension positions is shown in Table 4. The CI reached ±5.5° for the extension measurements; 95% of the EMS extension measurements were less than 5.6° different from the radiographic gold standard value. The Bland–Altman plots are shown in Fig. 5. Zero points for both extension and flexion ROM measurements were included within the 95% CI of the difference between the radiographic and EMS measurements.

Intra-rater and inter-rater ICCs for radiographic and EMS measurements are shown in Table 5. The ICC (1,3) indicating intra-rater reliability for radiographic and EMS measurements was 1.000 and 0.998, respectively. The ICC (2,3) indicating inter-rater reliability for radiographic and EMS measurements was 0.999 and 0.998, respectively.

| Table 3 | Comparison of the difference and correlation between radiographic and EMS measurements |
|---------|--------------------------------------------------------------------------------------|
| Range of motion | Radiographic measurement Mean ± SD (°) | EMS measurement Mean ± SD (°) | Pearson correlation coefficient between both methods (p value) |
| Extension | 2.7 ± 2.0 | 4.7 ± 3.0 | 0.41 (p = 0.012) |
| Flexion | 130.8 ± 4.5 | 131.8 ± 13.0 | 0.56 (p = 0.0004) |

| Table 4 | Bland–Altman analysis of difference between radiographic and EMS measurements |
|---------|--------------------------------------------------------------------------------|
| Range of motion | Mean ± SD of difference (°) | Upper 95% CI limit (mean + 1.96SD) | Lower 95% CI limit (mean − 1.96SD) | Absolute maximal error (± 1.96SD) |
| Extension | 20.0 ± 2.8 | 7.6 | −3.5 | ±5.5 |
| Flexion | 10.0 ± 11.2 | 22.9 | −20.9 | ±21.9 |

| Table 5 | Intra-rater and inter-rater ICCs for radiographic and EMS measurements of in vivo elbow joints |
|---------|----------------------------------------------------------------------------------|
|         | Radiographic measurement | EMS measurement |
| Intra-rater reliability | Mean ICC (1,3) | 1.000 | 0.998 |
| 95% CI | 0.999–1.000 | 0.995–0.999 |
| Inter-rater reliability | Mean ICC (2,3) | 0.999 | 0.998 |
| 95% CI | 0.997–1.000 | 0.993–0.999 |

Fig. 5 Bland–Altman plot. A Maximum extension of the elbow joint. B Maximal flexion of the elbow joint. Bland–Altman plots representing mean differences and 95% limits of agreement between the radiographic measurements and the EMS measurements of maximum elbow flexion and extension ROM. The middle line represents the mean difference, whereas the upper and lower lines indicate the 95% CI.
Discussion
Precise measurement of joint ROM is very important for treatment outcome assessments and reporting clinical research. The UG is a common clinical instrument used to evaluate the elbow joint and other major joints [1, 22, 23]. On the other hand, the reliability of the UG measurements is still under debate; the overall reliability of the UG measurements ranges from poor to excellent depending on the study. Fair to excellent reliability has been reported for the extension and flexion of elbow joints, with an intra-rater reliability of 0.45–0.99 and an inter-rater reliability of 0.53–0.98 [1, 6, 23–27]. Whether the examiner is an expert or a non-expert has some effect on the reliability of UG; Blonna et al. reported a lower inter-rater reliability of UG measurements in non-experts than in experts [28]. While radiographic measurements have the advantage of being very accurate due to the absence of soft tissue effects, they have the disadvantage of exposing the examinee to radiation [6, 16, 29]. In recent years, smartphone applications have been developed to measure ROM of the elbow joint; however, Vauclair et al. reported that the application measurements were not as accurate as the UG measurements and showed a tendency to overestimate the flexion angle measurement [30].

The EMS has shown high accuracy and reliability in the evaluation of knee instability associated with ACL injuries [7–13]. In this study, a new measurement method of ROM of the elbow joint using three-dimensional EMS was developed. The accuracy and reproducibility of the EMS measurement of elbow ROM were evaluated using a model bone that was not affected by the soft tissue. As a result of the accuracy assessment of the EMS measurements, the error between the mean measurement angle with the EMS and the actual measurement angle was less than 1.7° in all circumstances, the SD was less than 2.7°, and the Pearson’s correlation coefficient was 0.999 (p<0.0001), indicating high accuracy. Similarly, intra-rater and inter-rater reliabilities were calculated using the ICC for the reproducibility of the EMS measurements, and both ICC (1,10) and ICC (2,10) showed high reproducibility of 1.00. The values of the correlation coefficient were categorized according to this classification: slight; 0.00–0.20, fair; 0.21–0.40, moderate; 0.41–0.60, substantial; 0.61–0.80, and almost perfect; 0.81–1.00 [31].

Regarding the in vivo assessment, the EMS measurements for extension showed a similar SD to the radiographic measurements. On the other hand, the EMS measurements for flexion showed a larger SD of 13.0° compared to the radiographic measurements, resulting in increased variability. There were significant correlations between the EMS and radiographic measurements for both extension and flexion. In addition, the Bland–Altman analysis, which is currently the most commonly used method for comparative studies, was also used to evaluate the EMS and radiographic measurements [21]. In the current study, the 95% limit of agreement (LOA) was calculated as the mean difference ± 1.96 × SD according to Bland and Altman’s method [32], and the 95% LOA Bland–Altman plots (Fig. 5) indicated that the two methods were almost in agreement for both extension and flexion. While the Bland–Altman plots for extension and flexion showed that there was no fixed error because the zero point was within the 95% LOA range, the flexion measurements showed the presence of proportional error, where the difference between the EMS and radiographic measurements increased as the measurement angle increased. This result could be supported by the increase in the SD of the EMS measurements for flexion compared with radiographic measurements. The results of the in vivo flexion measurements in the EMS measurements suggest that the sensors on the brace attached to the upper arm and forearm were slightly displaced by the contraction of the biceps during flexion. For the reproducibility of in vivo EMS measurements, intra-rater and inter-rater reliabilities were calculated using the ICC, and both the ICC (1,3) and ICC (2,3) showed a high reproducibility of 0.998. A previous report showed that the ICCs of the radiographic method ranged from 0.980 to 0.991 (6); the reliability of both methods in this study was also comparable.

There are no reports that have evaluated the ROM measurement of the elbow joint with EMS measurement and compared it to the radiographic measurement, which is the gold standard for accuracy. This new method of measuring the ROM of the elbow joint using the three-dimensional EMS showed quite high intra-rater and inter-rater reliabilities. This result suggests that EMS measurement has high accuracy, reliability, and reproducibility. Additionally, the advantages of this system are that it is non-invasive and that the sample rate of the EMS is 60 Hz, allowing for near-real-time measurements. The application of EMS to the elbow joint shown in this study and the real-time evaluation of EMS could allow further evaluation of acceleration, including evaluation of elbow joint instability in the future.

This study has several limitations. First, the effect of displacement of the sensors on the braces attached to the upper arm and forearm was not considered in this study. Considering that the validity of the SD is much less in the flexion measurement by EMS, the proportional error in flexion measurements shown by the 95% LOA Band–Altman plots between the radiographic and the EMS measurement may indicate soft tissue effects. Second, the sample size was small.
The sample size for this study was calculated using G*Power (v 3.1; Universität Düsseldorf) with a priori power analysis \((\alpha < 0.05, 1 - \beta \geq 0.8)\) based on the similar previous study [30], showing \(n = 5\) for flexion measurements and \(n = 7\) for extension measurements. Considering this, it is suggested that the sample size number in this study is not extremely too small. Third, the subjects of this study were limited to healthy volunteers with no history of elbow joint disease. Therefore, this study did not evaluate the influence of elbow joint deformities resulting from traumatic fractures or epiphyseal line injuries on the accuracy of EMS. Although the elbow deformity is expected to affect the measurement of ROM not only in EMS in this study but also in UG and radiographic measurement, there is no report that evaluates it to the best of our knowledge and we would like to evaluate it in further studies in the future.

Conclusions
This method of measuring the ROM of the elbow joint using the EMS showed high accuracy, reliability, and reproducibility. The current study results demonstrated the possibility of using an electromagnetic system to provide an accurate evaluation of the elbow joint in clinical settings.

Abbreviations
ROM: Range of motion; EMS: Electromagnetic sensor system; ICC: Intraclass correlation coefficient; UG: Universal goniometer; LOA: Limit of agreement.

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Authors' contributions
KY, YM, AI, and KN contributed to the conception and design of the study. KY, TKA, TKU, and SM performed the experiments and collected the data. Data and statistical analysis were done by KY, YM, AI, and HN. Manuscript preparation was done by KY, YH, and TN. Supervising was done by RK. The authors read and approved the final manuscript.

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

Declarations
Ethics approval and consent to participate
Our Institutional Review Board (IRB) at Kobe University provided the approval for our study, and the approval information is Permission Number 8210009. 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.

Competing interests
The authors declare that they have no competing interests.

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References
1. Armstrong AD, MacDermid JC, Chinchalkar S, Stevens RS, King GJ. Reliability of range-of-motion measurement in the elbow and forearm. J Shoulder Elbow Surg. 1998;7(6):573–80.
2. Clar C, Cummins E, McIntyre L, Thomas S, Lamb J, Bain L, et al. Clinical and cost-effectiveness of autologous chondrocyte implantation for cartilage defects in knee joints: systematic review and economic evaluation. Health Technol Assess. 2005;9(47):iii–ix, ix–x, 1–82.
3. Youdas JW, Bogard GL, Suman VJ. Reliability of goniometric measurements and visual estimates of ankle joint active range of motion obtained in a clinical setting. Arch Phys Med Rehabil. 1993;74(10):1113–8.
4. Riddle DL, Rothstein JM, Lamb RL. Goniometric reliability in a clinical setting. Shoulder measurements. Phys Ther. 1987;67(5):668–73.
5. Park W, Ramachandran J, Weisman P, Jung ES. Obesity effect on male active joint range of motion. Ergonomics. 2010;53(1):102–8.
6. Chapleau J, Canet F, Petit Y, Lafamme GY, Roulleau DM. Validity of goniometric elbow measurements: comparative study with a radiographic method. Clin Orthop Relat Res. 2011;469(11):3134–40.
7. 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(7):1098–104.
8. 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(6):792–802.
9. Hoshino Y, Araujo P, Irngang JJ, Fu FH, Mushah V. An image analysis method to quantify the lateral pivot shift test. Knee Surg Sports Traumatol Arthrosoc. 2012;20(4):703–7.
10. Araki D, Kuroda R, Nishimoto T, Matsuoka 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(6):1053–62.
11. Hoshino Y, Araujo P, Ahldén M, Samuelsson K, Muller B, Hofbauer M, et al. Quantitative evaluation of the pivot shift test by image analysis using the iPad. Knee Surg Sports Traumatol Arthrosoc. 2013;21(4):975–80.
12. Nogai K, Hoshino Y, Nishizawa Y, Araki D, Matsuoka 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. 2015;23(10):2876–81.
13. 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 Arthrosoc. 2018;26(9):2835–40.
14. Milne AD, Chess DG, Johnson JA, King GJ. Accuracy of an electromagnetic tracking device: a study of the optimal range and metal interference. J Biomech. 1996;29(6):791–3.
15. Good ES, Suntay WJ. A joint coordinate system for the clinical description of three-dimensional motions: application to the knee. J Biomech Eng. 1983;105(2):136–44.
16. Szulc P, Lewandowski J. Verification of selected anatomical landmarks used as reference points for universal goniometer positioning during elbow joint mobility range measurements. Folia Morphol. 2003;62(4):353–5.
17. London JT. Kinematics of the elbow. J Bone Joint Surg Am. 1981;63(4):529–35.
18. Bland JM, Altman DG. A note on the use of the intraclass correlation coefficient in the evaluation of agreement between two methods of measurement. Comput Biol Med. 1990;20(5):337–40.
19. Bland JM, Altman DG. Applying the right statistics: analyses of measurement studies. Ultrasound Obstet Gynecol. 2003;22(1):85–93.
20. Lee J, Koh D, Ong CN. Statistical evaluation of agreement between two methods for measuring a quantitative variable. Comput Biol Med. 1989;19(1):61–70.
21. Myles PS, Cui J. Using the Bland–Altman method to measure agreement with repeated measures. Br J Anaesth. 2007;99(3):309–11.
22. Fowers KR, Stephens-Chisar J, LaStayo P, Galante BL. Intrarater reliability of a new method and instrumentation for measuring passive supination and pronation: a preliminary study. J Hand Ther. 2001;14(1):30–5.
23. Rothstein JM, Miller PJ, Roettger RF. Goniometric reliability in a clinical setting. Elbow and knee measurements. Phys Ther. 1983;63(10):1611–5.
24. Fieseler G, Mollitor T, Irlenbusch L, Delank KS, Laudner KG, Hermassi S, et al. Intrarater reliability of goniometry and hand-held dynamometry for shoulder and elbow examinations in female team handball athletes and asymptomatic volunteers. Arch Orthop Trauma Surg. 2015;135(12):1719–26.
25. Zwerus EL, Willigenburg NW, Scholtes VA, Somford MP, Egyendaal D, van den Beikerom MP. Normative values and affecting factors for the elbow range of motion. Should Elb. 2019;11(3):215–24.
26. Goodwin J, Clark C, Deakes J, Burdon D, Lawrence C. Clinical methods of goniometry: a comparative study. Disabil Rehabil. 1992;14(1):10–5.
27. van Rijn SF, Zwerus EL, Koenraadt KL, Jacobs WC, van den Beikerom MP, Egyendaal D. The reliability and validity of goniometric elbow measurements in adults: A systematic review of the literature. Should Elb. 2018;10(4):274–84.
28. Blonna D, Zarkadas PC, Fitzsimmons JS, O’Driscoll SW. Accuracy and interobserver reliability of visual estimation compared to clinical goniometry of the elbow. Knee Surg Sports Traumatol Arthrosc. 2012;20(7):1378–85.
29. Fish DR, Wingate L. Sources of goniometric error at the elbow. Phys Ther. 1985;65(11):1666–70.
30. Vauclair F, Aljurayyan A, Abduljabbar FH, Barimani B, Goetti P, Houghton F, et al. The smartphone inclinometer: a new tool to determine elbow range of motion? Eur J Orthop Surg Traumatol. 2018;28(3):415–21.
31. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977;33(1):159–74.
32. Bland JM, Altman DG. Measuring agreement in method comparison studies. Stat Methods Med Res. 1999;8(2):135–60.

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