ORIGINAL ARTICLE

Effects of forearm position on the range of motion in radio-ulnar deviation of the wrist joint

Tomohiro OHGOMORI

Department of Rehabilitation, Osaka Kawasaki Rehabilitation University
Correspondence: Tomohiro Ohgomori, PhD, Department of Rehabilitation, Osaka Kawasaki Rehabilitation University, 158 Mizuma, Kaizuka, Osaka, 597-0104, Japan. Tel: 81-72-446-6700 FAX: 81-72-446-6767
E-mail: ohgomorit@kawasakigakuen.ac.jp
Disclosure: The author has no potential conflicts of interest to disclose.

Key words: *range of motion, wrist joint, forearm position, ligaments*

Abstract

Background: Impairment of range of motion (ROM) in the wrist joint can strongly affect activities of daily living. The ROM of the wrist joint is therefore an important consideration when performing physical therapy. Academic societies worldwide have established and standardized measurement methods of the wrist joint ROM. The influence of measurement position of the forearm on the wrist joint ROM has been investigated in many biological studies using soft cadavers, but it has rarely been investigated *in vivo*.
Methods: First, we measured and examined the difference of the wrist joint ROM in pronation and in supination of the forearm in healthy young male adults. In the second part of the study, we also measured the change in tension of artificial ligaments attached to the free upper limb bones using strain gauges to specifically examine the effect of forearm position on the tension of ligament. We believe this is a representative limitation factor of joint motion.
Results: The ROM of radial deviation was smaller in supination of the forearm than in pronation. Meanwhile, the ROM of ulnar deviation was larger in supination of the forearm than in pronation. The total tension of the ulnar collateral and palmar ulnocapitate ligaments was larger than that of dorsal radiocarpal, palmar radiolunate, and radial collateral ligaments in supination of the forearm.
Conclusions: The ROM of radial deviation is indicated by our data to be restricted due to the higher tension in the ulnar extrinsic ligaments under supination of the forearm position compared with pronation.

INTRODUCTION

The wrist joint is involved in many functional activities in daily life, but it is at high risk of trauma and inflammatory diseases. For instance, the ranges of motion (ROMs) of palmar-dorsiflexion and radio-ulnar deviations are reportedly smaller in patients with distal radius fracture than in healthy controls (Yang, 2018). In patients with rheumatoid arthritis, pain reportedly occurs not only in the metacarpophalangeal joints, but also in the wrist joints; in at least one study, the ROM scores in the wrist joint were lower than those in healthy controls (Zhang, 2018). When performing physical therapy for such patients, it is important to consider the standard ROM of the wrist joint.

In Japan, general methods for physical therapy are established by the Japanese Orthopedic Society and the Japanese Society of Rehabilitation Medicine. The motion patterns of the wrist joint, which has two degrees of freedom, are palmar-dorsiflexion and radio-ulnar deviation (Rainbow, 2016). The ROM of palmar-dorsiflexion is typically measured in a neutral forearm position, and the basic and moving axes are set at the radius and the second metacarpal bone, respectively. The reference ROM for palmar flexion is 0-90◦, and that for dorsal flexion is 0-70◦. By contrast, the ROM of radio-ulnar deviation is measured with the forearm in pronation, and the basic and moving axes are set at the center of forearm and the third metacarpal bone, respectively. The reference ROM for radial deviation is 0-25◦, and that for ulnar deviation is 0-55◦. These reference ROMs are also supported by recent studies that used inertial sensor and smartphone photography (Costa, 2020; Rainbow, 2016; Surangsrirat, 2022). The position of the third metacarpal bone is easy to identify at the dorsal side compared with at the palmar side, so it is speculated that the wrist joint ROM of radial and ulnar deviation is best measured with the forearm in pronation. However, in daily life, the radio-ulnar deviations of the wrist joint are not necessarily performed in pronation, such as when turning keys, opening doors, and throwing balls. To perform physical therapy with activities of daily living in mind, it is important to determine measurement positions based on joint shape and axis identification, but there should also be consideration of the ROM in some of the diverse positions that may occur during daily activities. However, the difference of wrist joint ROM between pronated and supinated positions has not been sufficiently clarified.

The ROM is also reportedly affected by the measurement position. For instance, there are multiple measurement positions for rotational movements of the shoulder joint, and the ROM is different in each of them (Blaauw, 2014). In addition, some patients have negative ROM due to joint disease when ROM is measured in the basic position. (Steultjens, 2000). However, we suggest that in other positions, this ROM may be at least partially measurable. The influence of measurement positions on the joint ROM is therefore an important consideration. In the first measurement position of the shoulder joint ROM, the upper arm is kept in contact with the trunk and the elbow joint is bent to 90◦. The reference ROM of external rotation of the shoulder joint in this measurement position is 0-60◦ (Gill, 2020; Namdari, 2012). By contrast, in the second position, the reference ROM of external rotation is altered to 0-90◦ so that the shoulder joint is abducted 90◦ and the elbow joint flexes 90◦ (Sung, 2023). We suggest that this difference in reference ROM is related to the differing tension in the soft tissues surrounding the shoulder joint, such as ligaments, muscles, and joint capsules.

The length of the external ligaments crossing the wrist joint is reportedly changed by radial and ulnar deviations using *in vivo* 3D modeling analysis, and it is widely accepted that the tension of ligaments is an important factor in limitation of ROM (Xu, 2009). The influence of the forearm position on the tension and length of ligaments has also been examined using soft cadavers (DiTano, 2003). However, in one such soft cadaveric study, it was suggested that the forearm position does not affect the ROM of wrist joint (Kane, 2014). These studies provide important kinematic arguments, but it is difficult to truly understand *in vivo* kinematics from the use of cadaver specimens. There is also possibility that muscles and intrinsic ligaments influence the tension of extrinsic ligaments of the wrist joint.

We therefore believe that it is necessary to further consider the influence of forearm position on the mechanical properties of the wrist joint *in vivo*. In addition, we should also consider excluding indirect effects on the tension of extrinsic ligaments of the wrist joint. In the present study, we investigate the effect of forearm position on the wrist joint ROM in healthy male adults (rather than soft cadavers) for the first time. Moreover, we use artificial polychloroprene ligaments and a free upper bones model to measure the direct influence of forearm position on the extrinsic ligaments.

MATERIALS and METHODS

Ethical statements

All experiments were conducted in accordance with Declaration of Helsinki and were approved by the Osaka Kawasaki Rehabilitation University Ethics Committee (OKRU-RA0088). To avoid bias, no results were communicated to participants until the completion of the measurements. An optout approach was used to obtain informed consent from participants, to which all subjects agreed.

Measurement of ROM

It has been reported that there is no significant gender and age difference in the ROM of the wrist joint (Doriot, 2006; Nakatake, 2017). To simplify, 15 young male adults (age = 31.5 ± 9.5 years old) were recruited in this study. These research subjects each had healthy hands with no orthopedic disease. A total of 15 images acquired from each participant were used for the measurement of ROM in pronation and supination of the forearm with fingers fully adducted (neutral, n=3 images; active radial deviation, n=3 images, passive radial deviation, n=3 images; active ulnar deviation, n=3 images; passive ulnar deviation, n=3 images). ROM measurements for the right radial carpal joint were performed in a sitting position, with a table at approximately the same height as the elbow joint. The position of the upper arm is not specified in the general methods for measurement of ROM, but in the present study, the upper arm was placed parallel to the trunk and the elbow joint was bent to 90◦. To identify the distal end of the forearm, a small spherical marker (⌀=5 mm) was attached to the styloid process of the radius and a larger spherical marker (⌀=15 mm) was attached to the styloid process of the ulna. In addition, to identify the moving axis, two small spherical markers (⌀ = 5 mm) were attached to the third metacarpal bone. In order to keep the pronation angle of the forearm constant, participants were instructed to place the palmar surface on the table during radio-ulnar deviation. Similarly, to keep the supination angle of the forearm constant, participants were instructed to place the dorsal surface on the table during radial and ulnar deviation.

ImageJ, an open source software for processing and analyzing scientific images (https://imagej.net/), was used for the measurement of ROM. The center points were identified by drawing two arbitrary lines across the forearm proximal to the styloid processes of radius and ulna and then rotating these lines by 90◦. The 'basic axis' was defined as the straight line connecting the two center points. The 'moving axis' was defined as the straight line connecting the centers of the two small spherical markers on the third metacarpal bone. The angle formed by the basic and moving axes that was memorized in the ROI manager was calculated as the ROM in radio-ulnar directions.

Tension measurement of artificial ligament using strain gauges

The wrist joint is reinforced by many extrinsic ligaments (Kamal, 2016). In this study, we selected the following five ligaments because they were thought to have the potential to limit radioulnar deviation:

1) Dorsal radiocarpal ligament: between the styloid process of the radius and the dorsal area of the triquetral bone.
2) Palmar radiolunate ligament: between the styloid process of the radius and the palmar area of the lunate bone.
3) Palmar ulnocapitate ligament: between the styloid process of the ulna and the palmar area of the capitate bone.
4) Ulnar collateral ligament (UCL): between the styloid process of the ulna and the pisiform bone.
5) Radial collateral ligament: between the styloid process of the radius and the trapezium bone.

The radius, ulna, carpal bones, and phalanges were reconstructed using a synthetic resin based on the bones of a male young adult (Sakamoto Model Corporation, Mino City, Osaka, Japan). Measurement of ligament tension using this artificial bone model is novel and has previously untested. A metal female screw socket (19Φ M6; HILOGIK CO., Ltd., Osaka City, Japan) was attached to the proximal articular circumference of the radius, and it was screwed onto a manual rotation stage (RS-317; Chuo Precision Industrial Co., Ltd., Tokyo, Japan) using a full thread (M6×60 mm). The ulna and the radius were fixed with elastic rubber bands. The carpus and phalanges were assembled in the correct position using instant glue. Polychloroprene sheets (width = 5 mm) were attached between the carpus and phalanges as five artificial ligaments. We attached a strain gauge (length = 2 mm; BFLA-2-8LJCT, Tokyo Measurement Instrument Laboratory Co., Ltd., Tokyo, Japan) to the center of polychloroprene sheet using instant glue. Voltage changes of strain gauges were recorded with a multirecorder TMR-211 (Tokyo Measurement Instrument Laboratory Co., Ltd.). Plastic clay was attached in small amounts to distal end of ulna as an artificial triangular fibrocartilage complex, and the gap formed by the ulnar collateral ligament and triquetral was completely filled. The radial body is slightly curved, so the radial body was fixed using a double-opening clamp and the ulna was rotated. To measure pronation and supination angles, we attached a calibrated inertial sensor (IMS-SD; Tec Gihan Co., Ltd., Kyoto, Japan) to the olecranon. The trigger to begin measurement was inputted using a wireless trigger remote controller (WTRC-T; Tec Gihan Co., Ltd.). Pronation and supination were repeated 20 times, and the average voltage values were evaluated as the tension on artificial ligaments.

Statistical analysis

Data was statistically analyzed using KaleidaGraph 4.5 (Hulinks, Tokyo, Japan). The effects of forearm position on the angle of radioulnar flexion were statistically analyzed by paired *t* test. In this study, we only focused on the difference in ROM between pronation and supination of the forearm. p-value < 0.05 was considered statistically significant.

RESULTS

Effects of forearm position on the ROM of wrist joint during radial and ulnar deviation

We first examined the effects of forearm position on the ROM of wrist joint during radio-ulnar deviation. When we used a goniometer for the measurement of ROM, the reproducibility of measurements was affected by the definition of basic and moving axes. We therefore performed semi-automatic measurement of ROM using images acquired during the recording of measurement logs (Figure 1A-F). Both active and passive ROMs of the wrist joint during radial deviation were significantly smaller with supinated forearm than with pronated forearm. By contrast, both active and passive ROMs of the wrist joint during ulnar deviation were significantly larger with supinated forearm than with pronated forearm (Figure 1G). The total ROM of wrist joint was larger in supination than in pronation (Figure 1H).

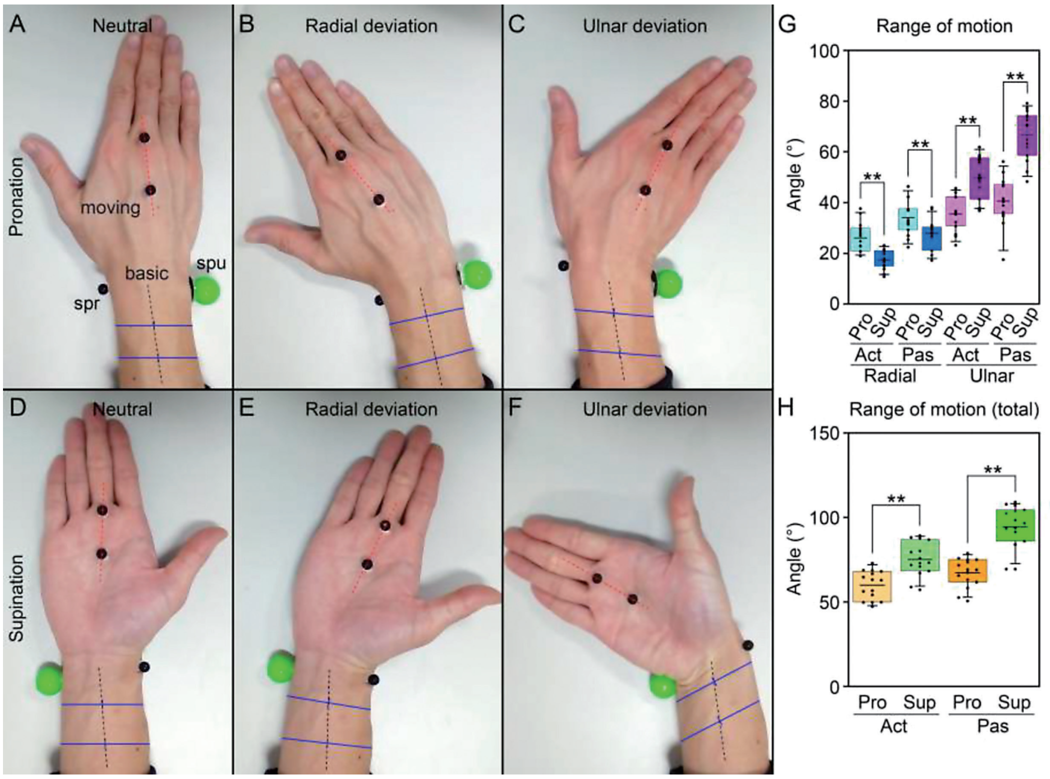

Figure 1. The influence of forearm position on the range of motion (ROM) of the wrist joint
(**A-C**) Representative images of the wrist joint in neutral (A), radial deviation (B), and ulnar deviation (C) positions with a pronated forearm (Pro). (**D-F**) Representative images of the wrist joint in neutral (D), radial deviation (E), and ulnar deviation (F) positions with a supinated forearm (Sup). Blue dashed lines indicate basic axes in the forearm. Red dashed lines indicate moving axes in the third metacarpal bone. spr, styloid process of radius; spu, styloid process of ulna. (**G**) The active (Act) and passive (Pas) ROMs of radial/ulnar deviation with the pronated and supinated forearm. (**H**) The total ROMs of wrist joint with the pronated and supinated forearm. Each circle represents the average angle for one participant. The box plots represent the median and the first and third quartiles (boxes), and the 5th and 95th percentile (whiskers). Number of participants was 15. Statistical significances: ** $p < 0.01$.

Effects of forearm position on the tension of artificial ligaments

Next, we examined the change in voltage of strain gauges attached to artificial ligaments, which restrict radio-ulnar deviation of the wrist joint (Figure 2A). Starting from a fully pronated forearm position, the voltage of strain gauges attached on artificial ligaments was measured during 20 cycles of pronation and supination (Figure 2B). The voltage of strain gauges attached to the artificial dorsal radiocarpal ligament was gradually increased by supination of the forearm. The voltage of strain gauges attached to the artificial palmar radiolunate ligament was remarkably increased by supination, it reached a plateau at the neutral position (90°) and then slightly decreased by further supination. The voltage of the strain gauge attached to the artificial radial collateral ligament was slightly decreased by supination from the pronated position, but it increased by further supination from the neutral position. The voltage of the strain gauge attached on artificial palmar ulnocapitate ligament was linearly increased by the supination. The voltage of the strain gauge attached to the UCL was gradually increased by supination from the pronated position. After 60° supination from the pronated position, there was a rapid decrease in voltage. Surprisingly, the voltage of the strain gauges attached to the UCL was remarkably increased by 120° supination from the pronated position (Figure 2C). Next, we investigated the total change in voltage of strain gauges attached to the artificial ligaments, which restrict radio-ulnar deviation (Figure 2D). The total voltage changes in strain gauges attached to the artificial ligaments restricting the ulnar deviation were linearly increased by the supination from the pronated position of the forearm. By contrast, the total voltage changes in strain gauges attached to the artificial ligaments restricting the radial deviation were transiently increased until the 120° supination from the pronated position of the forearm. It was rapidly re-increased by further supination, and became larger than the voltage of strain gauges attached to the artificial ligament restricting ulnar deviation at 150° supination of the forearm from the pronated position (Figure 2D).

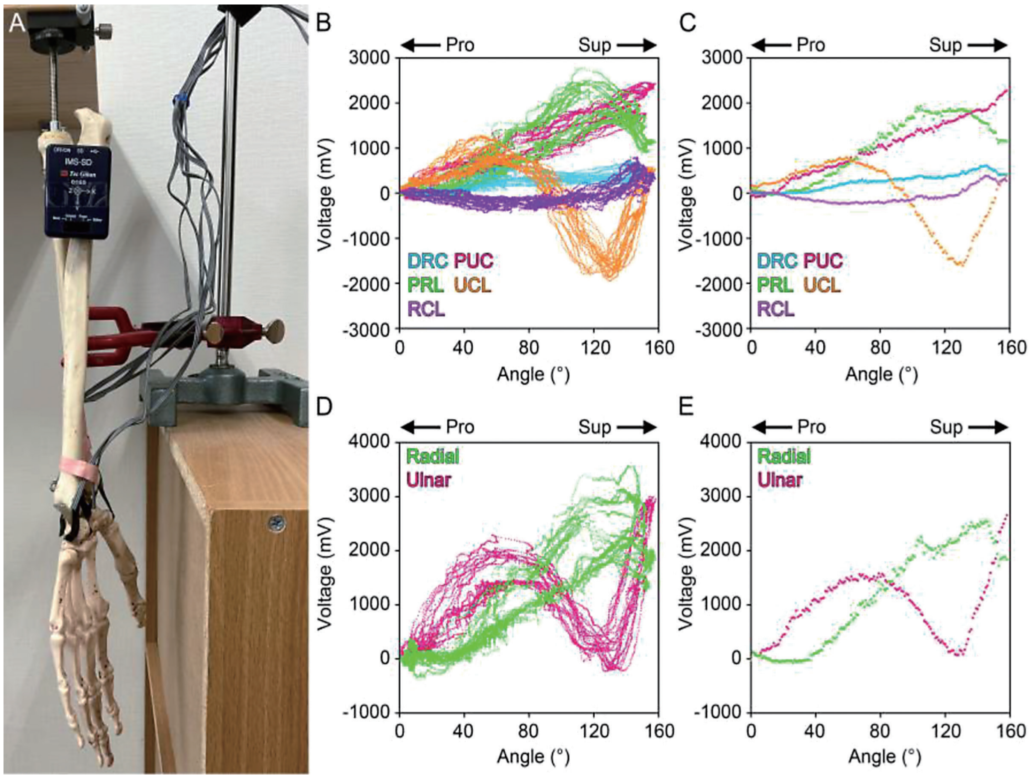

Figure 2. The influence of forearm position on the tension of artificial extrinsic ligaments
(**A**) The measurement system of tension of artificial extrinsic ligaments. (**B**) Raw data of changes in voltage of strain gauges attached on artificial ligaments measured during 20 times pronation and supination of the forearm. (**C**) The average value of change in voltage of strain gauges attached to each artificial ligament. (**D**) Raw data of total changes of voltage of strain gauges attached to radial/ulnar ligaments restricting the ulnar/radial deviation, respectively. (**E**) The average value of total change in voltage of strain gauges attached to radial/ulnar ligaments. Abbreviations: DRC, dorsal radiocarpal ligament; PRL, palmar radiolunate ligament; RCL, radial collateral ligament; PUC, palmar ulnocapitate ligament; UCL, ulnar collateral ligament (UCL).

DISCUSSION

We measured the ROM of radio-ulnar deviations of the wrist joint in pronated and supinated positions *in vivo*. In the basic pronated position, the passive ROM of radio-ulnar deviations was 34.1 ± 7.1° and 40.6 ± 9.2°, respectively. These were similar to previous results from studies which used a goniometer and inertial sensor (Jonsson, 2001; Yuine, 2023). This suggests that ImageJ analysis is viable in the measurement of ROM.

In supination, the passive ROM of radial and ulnar deviations were 27.8 ± 6.0° and 66.7 ± 9.6°, respectively. These were significantly different from those of radio-ulnar deviations in pronation. It is therefore surprising that the forearm position did not affect the ROM of wrist joint using soft cadavers in previous studies (Kane, 2014). We propose several possible reasons for these contrasting results. One reason is the difference in measurement targets. Although the results measured with soft cadavers are kinematically and biomechanically important, it can be quite difficult to apply them to *in vivo* kinematics. A second possible reason is that the flexors and extensors attached to the humerus and phalanges are structurally damaged during construction of the measurement system.

The difference in the ROM between pronation and supination was observed not only in active measurement, but also in passive measurement. This difference is suggested to be dependent on the soft tissues surrounding the wrist joint rather than the function of nerves, muscles, and tendons. The soft tissues across the wrist joint include muscles and ligaments. Generally, passive ROM is selectively influenced by the flexibility of antagonistic muscles and active ROM is influenced by the action of both agonistic and antagonistic muscles. If the forearm position changes the active ROM, it is suggested that the forearm position influences the action of the main agonistic muscle. Both passive and active ROM were influenced by forearm positions in our results, so it is possible that the forearm position affects the flexibility of antagonistic muscles and the limiting factors (e.g., ligaments) rather than the action of the main agonistic muscles involved in the radio-ulnar deviations. Muscles were attached to the distal carpal bones, while ligaments were attached to both the proximal and distal carpal bones (Kijima, 2009). These anatomical structures strongly indicate that the mobility of the wrist joint starts distally but terminal limitation of motion is caused by the soft tissues that are attached to the proximal carpal bones. Furthermore, previous MRI analysis has shown that the mobility of carpal bones is greater during radio-ulnar deviation than during palmar-dorsiflexion (Li, 2022). This indicates that the loads on the soft tissue are indicated to be greater during radio-ulnar deviation than during palmar-dorsiflexion. The proximal radio-ulnar joint consists of the radial notch on the ulna and the radial head. The distal radio-ulnar joint consists of the ulnar notch on the radius and the ulnar head. Therefore, the proximal center of rotation is located on the radius, and the distal center of rotation is located on the ulna (Shiode, 2024). In addition, the extrinsic ligaments of the wrist joint attach to the distal regions of both the radius and the ulna. The radius and carpal bones move together during pronation and supination of forearm, suggesting that the deviation of the ulnar ligaments is greater than that of the radial ligaments. The tensions of palmar ulnotriquetral and ulnolunate ligaments were higher in supination than in pronation in a previous study that used soft cadavers (DiTano, 2003). Consistent with this report, we revealed that the voltage of strain gauges attached to an artificial palmar ulnocapitate ligament was higher in supination than in pronation. The previous study also reported that the tension of the ulnocarpal collateral ligament was higher in supination than in pronation (DiTano, 2003). Although the increase of voltage in a strain gauge attached to the artificial UCL in the current study was observed from the fully pronated position to the intermediate position, it was transiently decreased by supination. Voltage of strain gauge attached to the center of the artificial UCL was not significantly different between pronation and supination. One possible explanation for this is that the center of the soft tissues may be twisted. The voltage of strain gauges decreases due to twisting and compression. When the radius and carpal bones rotate around the ulnar head, the UCL may be slightly twisted. The tension at the end of artificial ligaments may therefore be different from that at the center region. A second possibility is that the interaction between UCL and triangular fibrocartilage complex was ignored in our mechanical model due to technical limitations. This interaction may critically affect the torsion and tension of the UCL.

This study has some limitations. In the present mechanical study which used strain gauges, we ignored the effect of other ligaments connecting between carpal bones and we did not take into account the influence of flexor and extensor muscles beyond the wrist joint. These factors may have indirect effects on the tension of ligaments, so further studies using X-ray and ultrasound analyses are necessary. Moreover, we recognize there is a quite difference in the stiffness of biological ligaments compared with chloroprene rubber approximations for ligaments we used, which should be noted in applying the change in tension of artificial ligaments shown in this study to biological ligaments. Further research using soft cadavers may be effective in addressing these issues. Furthermore, the changing patterns in the voltage of strain gauges were in pronation and supination. The voltage changes of strain gauges attached to hard materials are similar between extension and compression according to manufacturer's instructions. Polychloroprene is the softest material in which the change in voltage can be measured by BFLA-2-8LJCT strain gauge according to the manufacturer's instructions, so it should be noted that the voltage changes are relative values based on fully pronated positions. Finally, in the present study, we examined the radio-ulnar ROM of the right wrist joint. However, the difference of ROM between dominant and non-dominant hands should also be considered.

CONCLUSIONS

This study suggests that the forearm position may affect the tension of extrinsic ligaments of the wrist joint, which are components unrelated to the shape of the wrist joint, and the ROM of radio-ulnar deviation. In daily life, radio-ulnar deviations of the wrist joint are performed not only in pronation (e.g. when wiping a table) but also in supination (e.g. when placing an object on the palm and shaking it), no matter how simple the movement. Determination of the measurement position based on the shape of the joint is therefore insufficient for the anatomical understanding of ROM. When performing physical therapy for patients with fractures and joint diseases it is necessary to consider the influence of a range of diverse positions on the wrist joint ROM.

REFERENCES

Blaauw G, Muhlig R. Measurement of external rotation of the shoulder in patients with obstetric brachial plexus palsy. J Brachial Plexus Peripher Nerve Inj 7(1), e24–e39, 2014 doi.org/10.1186/1749-7221-7-8

Costa V, Ramírez Ó, et al. Validity and reliability of inertial sensors for elbow and wrist range of motion assessment. PeerJ 8, e9687, 2020 doi.org/10.7717/peerj.9687

DiTano O, Trumble TE, et al. Biomechanical function of the distal radioulnar and ulnocarpal wrist ligaments. J Hand Surg Am 28(4), 622–627, 2003 doi.org/10.1016/S0363-5023(03)00183-7

Doriot N, Wang X. Effects of age and gender on maximum voluntary range of motion of the upper body joints. Ergonomics 49(3), 269–281, 2006 doi.org/10.1080/00140130500489873

Gill TK, Shanahan EM, et al. Shoulder range of movement in the general population: age and gender stratified normative data using a community-based cohort. BMC Musculoskelet Disord 21(1), 676, 2020 doi.org/10.1186/s12891-020-03665-9

Jonsson P, Johnson PW. Comparison of measurement accuracy between two types of wrist goniometer systems. Appl Ergon 32(6), 599–607, 2001 doi.org/10.1016/S0003-6870(01)00036-9

Kamal RN, Starr A, et al. Carpal kinematics and kinetics. J Hand Surg Am 41(10), 1011–1018, 2016 doi.org/10.1016/j.jhsa.2016.07.105

Kane P, Vopat B, et al. The effect of supination and pronation on wrist range of motion. J Wrist Surg 3(3), 187–191, 2014 doi.org/10.1055/s-0034-1384749

Kijima Y, Viegas SF. Wrist anatomy and biomechanics. J Hand Surg Am 34(8), 1555–1563, 2009 doi.org/10.1016/j.jhsa.2009.07.019

Li J, Rath B, et al. Wrist bone motion during flexion-extension and radial-ulnar deviation: an MRI study. Life 12(10), 1458, 2022 doi.org/10.3390/life12101458

Nakatake J, Totoribe K, et al. Influence of gender differences on range of motion and joint angles during eating in young, healthy Japanese adults. Prog Rehabil Med 2, 20170011, 2017 doi.org/10.2490/prm.20170011

Namdari S, Yagnik G, et al. Defining functional shoulder range of motion for activities of daily living. J Shoulder Elbow Surg 21(9), 1177–1183, 2012 doi.org/10.1016/j.jse.2011.07.032

Rainbow MJ, Wolff AL, et al. Functional kinematics of the wrist. J Hand Surg Eur Vol 41(1), 7–21, 2016 doi.org/10.1177/1753193415616939

Shiode R, Miyamura S, et al. Reproduction of forearm rotation dynamic using intensity-based biplane 2D–3D registration matching method. Sci Rep 14(1), 5518, 2024 doi.org/10.1038/s41598-024-55956-z

Steultjens MP, Dekker J, et al. Range of joint motion and disability in patients with osteoarthritis of the knee or hip. Rheumatology 39(9), 955–961, 2000 doi.org/10.1093/rheumatology/39.9.955

Sung JH, Jung W, et al. The effects of body positions and abduction angles on shoulder muscle activity patterns during external rotation exercises. Healthcare 11(14), 1977, 2023 doi.org/10.3390/healthcare11141977

Surangsrirat D, Bualuangngam T, et al. Comparison of the wrist range of motion measurement between inertial measurement unit glove, smartphone device and standard goniometer. Appl Sci 12(7), 3418, 2022 doi.org/10.3390/app12073418

Xu J, Tang JB. In vivo length changes of selected carpal ligaments during wrist radioulnar deviation. J Hand Surg Am 34(3), 401–408, 2009 doi.org/10.1016/j.jhsa.2008.11.013

Yang Z, Lim PPH, et al. Association of wrist and forearm range of motion measures with self-reported functional scores amongst patients with distal radius fractures: a longitudinal study. BMC Musculoskelet Disord 19(1), 142, 2018 doi.org/10.1186/s12891-018-2065-z

Yuine H, Mutsuzaki H, et al. Evaluation of hand functions and distal radioulnar joint instability in elite wheelchair basketball athletes: a cross-sectional pilot study. BMC Sports Sci Med Rehabil 15(1), 58, 2023 doi.org/10.1186/s13102-023-00658-8

Zhang L, Cao H, et al. Motion analysis of the wrist joints in Chinese rheumatoid arthritis patients: a cross-sectional study. BMC Musculoskelet Disord 19(1), 270, 2018 doi.org/10.1186/s12891-018-2146-z