



Original Article

Test-retest reliability of goniometric measurements of the range of dart-throwing motion

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Abstract. [Purpose] To examine the reliability of using a manual goniometer for measuring the range of dart-throwing motion. [Participants and Methods] The range of dart-throwing motion in 24 healthy participants was measured by three raters on the same day, and one rater repeated the measurement on another day of the same week. The stationary arm of the goniometer was placed along the radius, and the moveable arm was placed along the shaft of the second metacarpal, approximately 45° supinated from Lister's tubercle. All of the participants performed the dart-throwing motion on a plane that passed through the anatomical neutral wrist position, inclined 45° to the orthogonal anatomical plane. [Results] The intra-rater reliability was moderate (0.5–0.75) only for some parameters of the radial extension, and the intraclass correlation coefficients (ICCs) of all other parameters were <0.5. For the inter-rater reliability, the ICCs of all parameters were <0.5. Brand-Altman analysis revealed some fixed biases between the raters, although no proportional bias was observed. [Conclusion] The goniometric measurement procedure examined in this study appeared to be unsuitable for clinical use because of its poor reliability.

Key words: Wrist, Range of motion, Reliability

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INTRODUCTION

In many occupational and recreational activities such as hammering or clubbing, the wrist joint moves along the path from radial extension to ulnar flexion^{1–3}). As the motion along this path is similar to the act of throwing a dart, Palmer²) named it dart-throwing motion (DTM) and described it as a functional and natural motion of the wrist. In 2007, the International Federation of Societies for Surgery of the Hand defined the DTM as a plane in which wrist functional oblique motion occurs, specifically from radial extension to ulnar flexion⁴). Two types of DTM have been known to exist⁵). One is called functional DTM, and the other is pure DTM. The former is commonly performed in daily tasks, so it is regarded as the DTM itself in a narrow sense. The functional DTM usually does not intercept the coronal and sagittal planes at the zero position at the same time, which means that the wrist does not take a neutral position during its motion. By contrast, the pure DTM passes the neutral wrist position and is a particular motion, as it can only be performed purposely in situations such as in experimental settings.

The rotational axis of the midcarpal joint penetrates the capitate bone from the navicular tubercle to the hamate bone at an angle of 45° oblique to the rotational axis of pure flexion-extension in the coronal plane view^{6, 7}). According to the studies that investigated carpal kinematics, the midcarpal joint plays a central role in the DTM^{8–10}). A study¹¹) that examined the temporal changes of the radiographic findings of the carpus and wrist joint dynamics in patients after sustaining distal radial fractures demonstrated that the mobility of the midcarpal joint was restored earlier than that of the radiocarpal and that the

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range of DTM was fully recovered at the same time, whereas the ranges of the orthogonal anatomical direction remained limited. These results suggest that the range of DTM can also be an indicator of the mobility of the midcarpal joint in clinical practice. Meanwhile, studies^{12, 13)} that examined the relationships between range of wrist motion and Disability of the Arm, Shoulder and Hand (DASH) score revealed that the range of DTM was the only measure that correlated with the disability score. The DASH Outcome Measure is a self-report questionnaire designed to measure physical function and symptoms, and to describe the disability in upper limb disorders. These studies suggest that the range of DTM may be available as a sensitive reference to disabilities in activities of daily living.

Although the DTM has been recognized as an important functional motion of the wrist joint, to date, no standardized methods of goniometric measurement for this motion have been established yet. This might be because no measurement methods which are both reliable and convenient enough to withstand clinical use have been offered. In 2013, Bugden¹⁴⁾ proposed a method using a conventional goniometer for measuring the DTM and mentioned that further research was needed to determine the reliability of this tool. In his method, the stationary and movable arms of the goniometer were aligned to the longitudinal axis of the radius and shaft of the second metacarpal bone, respectively, and the functional DTM was targeted for the measurement. When the motion plane does not pass through the neutral wrist position, the direction of the longitudinal axis of the radius for the stationary axis becomes non-parallel to the motion plane of the dart throw. For this reason, we supposed that the functional DTM would be more complex to measure than the pure DTM and that this might have a potentially negative impact on the reproducibility of the measurement. Therefore, in the present study, we aimed to examine the reliability of goniometric measurement of the pure DTM, which passes through the neutral wrist position, while adhering to the goniometer placement defined by Bugden. We slightly modified his method by targeting the pure DTM instead of the functional DTM.

PARTICIPANTS AND METHODS

Twenty-four healthy participants (15 male and 9 female) with no history of orthopedic disease attended the experiment. The mean (range) age, height, and weight were 19.1 ± 0.7 years (18–21 years), 168.3 ± 9.4 cm (154–190 cm), and 59.8 ± 15.7 kg (41–110 kg), respectively. Of the participants, 23 were right-handed and one was left-handed.

As raters, three occupational therapists participated in this study. One rater had >20 years of clinical experience, and the other two had >10 years of clinical experience. They received an adequate explanation of the goniometric measurement procedure for the DTM and practiced for about 1 hour to ensure mastery of the skills in advance of the experiment.

Prior to enrollment, the participants were given an information sheet and provided written informed consent for participation. The participants were informed that participation was voluntary and they could withdraw at any point. Ethical approval for the study was granted by the research ethics committees of Shonan University (approval no. 16-005).

As the first measurement experiment, the range of DTM of each participant was measured three times by all raters on the same day, at an interval of 5 to 10 minutes between the raters. The order of raters was randomized for each participant. Each measurement was conducted with respect to active and passive ranges in the order of passive from active. None of the raters was permitted to watch any of the other examiners conduct the measurements or to access the results.

The second measurement experiment was conducted within a week after the first measurement experiment. In the second measurement experiment, all the measurements were conducted by one rater (the first author) who attended the first measurement experiment.

A digital goniometer (Digital protractor, Shinwa Rules Co. Ltd., Niigata, Japan) with a length of 200 mm and weight of 162 g (Fig. 1) was used in the measurement. One side of the goniometer was covered so that the raters could not read the angle. Instead, a dedicated recorder read the angles of the goniometer. To measure the range of DTM, the stationary arm of the goniometer was placed along the radius and the moveable arm was placed along the shaft of the second metacarpal bone, approximately 45° supinated from Lister's tubercle (Fig. 2). As the goniometer comes in contact with the brachioradialis on the part of the radius, the stationary arm becomes easily misaligned with the long axis of the radius. Therefore, attention was paid to press the goniometer strongly on this site.

During the measurement, the participant was seated on a chair, with the shoulder in neutral position, the elbows at 90° flexion, and the forearm at 45° pronation. To confirm the position of the forearm at 45° pronation, a conventional manual goniometer with exposed scales was used. The stationary and movable arms of the goniometer were aligned to the long axis of the humerus and on the volar site of the distal portion of the metacarpal bones, respectively. Except for pronation, other positions were confirmed visually by the rater. Once these positions were obtained, the participant was asked not to change them until the measurement was completed. Finger position was not defined especially.

To achieve the DTM, the participants were instructed to move their wrists vertically through the neutral wrist position so that the plane of the second metacarpal motion became parallel to the sagittal plane of the humeral bone while maintaining the above-mentioned positions. Then, the measurement was taken in an oblique plane of 45° from the flexion-extension arc, that is, 45° supinated from Lister's tubercle, regarding the direction of from radial extension (Fig. 3) to ulnar flexion (Fig. 4). At the orientation, the participants were instructed how to move the wrist while performing the real motion under the assistance of the examiner, rather than with only a verbal explanation, so that they could better understand the correct movement.

Intraclass correlation coefficients (ICCs) were used to determine the intra-rater (model 1, 1; model 1, 2; and model 1, 3)

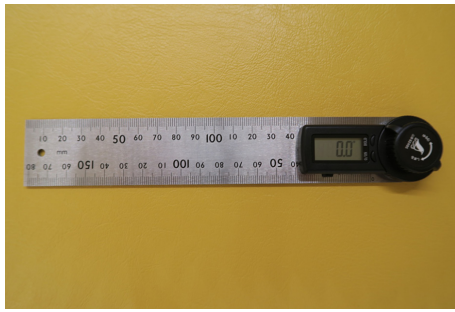


Fig. 1. Digital goniometer.



Fig. 2. Placement of the goniometer. The moveable arm of the goniometer is placed along the radial aspect of the shaft of the second metacarpal bone. The stationary arm is placed along the radial aspect of the radius, approximately 45° supinated from Lister's tubercle.



Fig. 3. Measurement of radial extension.



Fig. 4. Measurement of ulnar flexion.

and inter-rater reliabilities (model 2, 1; model 2, 2; and model 2, 3). ICC was calculated for the radial extension, ulnar flexion, and their sum (total motion), both in the active and passive measurements. Reliability was defined as poor (ICC<0.50), moderate (ICC 0.50–0.75), or good (ICC>0.75) using previously established criteria¹⁵⁾. Statistical calculations were performed using the IBM SPSS Statistics 23 (IBM Japan, Tokyo, Japan).

To account for the systematic bias between the first and second measurement experiments, Bland-Altman methods were used. Calculations included the 95% confidence interval for the mean difference, the regression between the difference and the mean of the two paired measures, and the 95% confidence interval of the minimal detectable change (MDC₉₅). The MDC₉₅ was calculated using the specific equation ($MDC_{95}=1.96 \times SD_d$, where SD_d is the standard deviation of difference).

RESULTS

Table 1 shows the descriptive statistics for each variable. Table 2 shows the intra-rater reliability for each measurement. The ICCs for the measurements in 1° and 5° were similar in all the parameters. Although the reliabilities were moderate only for some parameters of the radial extension, the ICCs of all the others were <0.5, indicating poor reliability.

Table 3 shows the inter-rater reliability for each measurement. The ICCs for the measurements in 1° and 5° were similar in all the parameters. The ICCs of all the parameters were <0.5, indicating poor reliability.

Table 4 shows the results of the Bland-Altman analysis. Some fixed biases were observed between the raters, although no proportional bias existed.

DISCUSSION

In 2012, Kasubuchi et al.^{16, 17)} developed a dedicated device to measure the range of DTM and examined its reliability.

Table 1. Results of descriptive statistics of measured ROM (degrees)

	Radial extension		Ulnar flexion		Total range	
	Active ROM	Passive ROM	Active ROM	Passive ROM	Active ROM	Passive ROM
First measure experiment						
Rater 1						
1st	47.19 ± 10.28	55.04 ± 9.56	47.74 ± 8.44	57.19 ± 11.29	94.93 ± 12.97	112.23 ± 16.41
1st–2nd	47.65 ± 9.22	56.37 ± 7.0	48.28 ± 8.02	57.74 ± 10.59	95.94 ± 12.55	114.11 ± 13.92
1st–3rd	47.71 ± 8.76	56.72 ± 7.86	48.37 ± 8.44	58.11 ± 10.4	96.09 ± 12.35	114.83 ± 13.44
Rater 2						
1st	54.82 ± 15.62	68.64 ± 13.3	46.52 ± 10.28	51.31 ± 10.27	101.34 ± 18.96	119.95 ± 17.85
1st–2nd	55.18 ± 14.75	68.39 ± 13.15	46.06 ± 9.58	51.95 ± 9.83	101.24 ± 17.39	120.34 ± 17.06
1st–3rd	55.18 ± 14.23	68.74 ± 12.57	46.79 ± 9.83	52.58 ± 9.4	101.97 ± 17.16	121.32 ± 16.97
Rater 3						
1st	48.5 ± 10.7	57.39 ± 10.78	40.22 ± 8.92	43.18 ± 8.92	88.71 ± 14.76	100.57 ± 15.17
1st–2nd	47.0 ± 9.76	57.34 ± 10.36	38.89 ± 7.37	43.51 ± 7.04	86.86 ± 14.13	100.85 ± 13.75
1st–3rd	47.21 ± 9.51	57.2 ± 10.4	39.05 ± 7.26	44.02 ± 6.53	86.26 ± 14.11	101.22 ± 13.9
Second measure experiment						
Rater 1						
1st	48.03 ± 8.92	53.81 ± 8.49	48.6 ± 10.2	59.55 ± 8.94	96.63 ± 14.74	113.35 ± 12.66
1st–2nd	46.38 ± 7.38	54.07 ± 8.54	49.25 ± 8.78	59.23 ± 7.82	95.63 ± 11.91	113.29 ± 12.36
1st–3rd	45.97 ± 7.26	54.21 ± 8.62	49.19 ± 8.65	58.88 ± 7.83	95.16 ± 11.82	113.09 ± 12.59

Values are mean ± SD.

ROM: range of motion; 1st: value of first measurement; 1st–2nd: mean value of 1st to 2nd measurement; 1st–3rd: mean value of 1st to 3rd measurement.

They reported good reliabilities for both intra- and inter-raters. However, compared with the conventional goniometer, their device was not downsized. The shape was 170 mm in width, 482 mm in depth, and 150 mm in height, with a weight of 1.4 kg. This seems to be a disadvantage for clinical application. Meanwhile, in 2018, Vardakastani et al.¹⁸⁾ described a method that uses a conventional goniometer for measuring the functional DTM. In their report, goniometry was initially not able to quantify the range of DTM accurately, although a correction equation that takes values of flexion, extension and ulnar deviation angle measured simultaneously as input variables enables the measurement to be used with confidence as part of clinical assessment.

The proposed method by Bugden¹⁴⁾ uses the task of simulated hammering to produce the DTM while having the subject grasp a real hammer. According to a survey¹⁹⁾ that evaluated the wrist kinematics during the hammering task, the trajectory of the motion was shown to be linear, and the motion plane was found not to pass the anatomical neutral wrist position, which means that this motion was the functional DTM. Therefore, in the present study, we changed Bugden's method into performing the pure DTM instead of the simulated hammering to ensure high test reliability. Despite our assumption, however, this study showed a poor reliability for both the intra- and inter-raters, except for some conditions of radial extension. Furthermore, some fixed biases were also observed between the raters. The goniometric measurement procedure examined in this study appeared to be unsuitable for clinical use because of its poor reliability.

The pure DTM is a specific motion that is not usually performed in everyday life. Therefore, if performed voluntarily, its reproducibility could be decreased. In our method, the participants were asked to take the wrist in neutral position initially and to move it parallel to the sagittal plane of the humerus while keeping the forearm positioned at 45° pronation. Paying attention concurrently to all these points during the measurement might be difficult for the participants. The poor reliability of our results might be due to the possible change of the direction or planar shape of the motion plane in each participant. In our study, however, wrist motion was not analyzed quantitatively and no conclusive evidence was obtained on how the wrist motion was actually performed. This was a limitation of our study.

As mentioned above, Vardakastanis' method corresponds to the functional DTM, and was initially not able to quantify the motion accurately. The functional DTM, which has a confirmed linear trajectory, does not change the planar shape of the motion plane^{2, 3, 19)}. In Vardakastanis' method, placement of the arms of goniometer was same as our study. From these points, our results might be also due to the manner of goniometer placement. Particularly when aligning the stationary arm of the goniometer, the longitudinal axis of the radius was difficult to identify visually from the aspect of 45° supination from Lister's tubercle because of the thick soft tissue covering this site. This could be a cause of the poor reliability. Thus, to ensure reliable measurements, the setting for the goniometer placement might have to be put on the review in future studies.

Further studies are required to develop a method for measuring the range of DTM that is reliable and easy to apply for wider use in clinical settings.

Funding and Conflict of interest

There are no acknowledgments of financial support and the conflicts of interest for any of the authors.

Table 2. Intra rater reliability for measurement

	Reading of 1 degree interval			Reading of 5 degrees interval		
	ICC _{1,1} (95% CI)	ICC _{1,2} (95% CI)	ICC _{1,3} (95% CI)	ICC _{1,1} (95% CI)	ICC _{1,2} (95% CI)	ICC _{1,3} (95% CI)
Radial extension						
Active ROM	0.49 (0.12 to 0.74)	0.53 (0.18 to 0.77)	0.51 (0.15 to 0.75)	0.47 (0.1 to 0.73)	0.48 (0.11 to 0.73)	0.51 (0.15 to 0.75)
Passive ROM	0.43 (0.05 to 0.71)	0.5 (0.13 to 0.74)	0.45 (0.07 to 0.72)	0.47 (0.09 to 0.73)	0.51 (0.15 to 0.75)	0.47 (0.09 to 0.73)
Ulnar flexion						
Active ROM	0.1 (-0.31 to 0.47)	0.22 (-0.19 to 0.57)	0.29 (-0.11 to 0.62)	0.09 (-0.32 to 0.46)	0.22 (-0.19 to 0.57)	0.3 (-0.1 to 0.62)
Passive ROM	0.07 (-0.33 to 0.45)	0.23 (-0.18 to 0.57)	0.29 (-0.12 to 0.61)	0.07 (-0.33 to 0.45)	0.24 (-0.17 to 0.58)	0.27 (-0.14 to 0.6)
Total range						
Active ROM	0.3 (-0.1 to 0.62)	0.36 (-0.04 to 0.66)	0.39 (0.01 to 0.68)	0.3 (-0.09 to 0.63)	0.34 (-0.06 to 0.65)	0.39 (-0.05 to 0.58)
Passive ROM	0.31 (-0.09 to 0.63)	0.37 (-0.03 to 0.67)	0.34 (-0.06 to 0.65)	0.37 (-0.27 to 0.67)	0.4 (0.03 to 0.69)	0.36 (-0.04 to 0.66)

Readings of 5 degrees interval means that the data were estimated based on the readings of a 5 degrees interval.

ICC: intraclass correlation coefficient; CI: confidence interval; ROM: range of motion.

Table 3. Inter rater reliability for measurement

	Reading of 1 degree interval			Reading of 5 degrees interval		
	ICC _{2,1} (95% CI)	ICC _{2,2} (96% CI)	ICC _{2,3} (97% CI)	ICC _{2,1} (95% CI)	ICC _{2,2} (96% CI)	ICC _{2,3} (97% CI)
Radial extension						
Active ROM	0.36 (0.11 to 0.61)	0.38 (0.13 to 0.63)	0.39 (0.14 to 0.64)	0.34 (0.09 to 0.6)	0.38 (0.13 to 0.63)	0.38 (0.13 to 0.63)
Passive ROM	0.34 (0.09 to 0.6)	0.33 (0.08 to 0.59)	0.31 (0.06 to 0.57)	0.31 (0.06 to 0.58)	0.33 (0.08 to 0.59)	0.31 (0.06 to 0.57)
Ulnar flexion						
Active ROM	0.35 (0.09 to 0.6)	0.22 (-0.02 to 0.5)	0.16 (-0.07 to 0.44)	0.36 (0.1 to 0.6)	0.2 (-0.04 to 0.48)	0.16 (-0.07 to 0.45)
Passive ROM	0.02 (-0.21 to 0.25)	0.06 (-0.16 to 0.34)	0.07 (-0.15 to 0.35)	0.02 (-0.18 to 0.3)	0.08 (-0.14 to 0.37)	0.07 (-0.14 to 0.36)
Total range						
Active ROM	0.28 (0.04 to 0.55)	0.33 (0.08 to 0.59)	0.33 (0.08 to 0.59)	0.3 (0.05 to 0.57)	0.33 (0.08 to 0.59)	0.33 (0.08 to 0.59)
Passive ROM	0.28 (0.03 to 0.55)	0.29 (0.05 to 0.56)	0.26 (0.01 to 0.53)	0.31 (0.06 to 0.58)	0.31 (0.06 to 0.58)	0.26 (0.02 to 0.53)

Readings of 5 degrees interval means that the data were estimated based on the readings of a 5 degrees interval.

ICC: intraclass correlation coefficient; CI: confidence interval; ROM: range of motion.

Table 4. Bland-Altman analysis for intra rater

Inter-rater	95%CI (degree)						p value	Proportional bias	MDC ₉₅ (degree)
	95%CI (degree)	Fixed bias	Regression	Regression	p value	Proportional bias			
between rater A and rater B									
Active ROM	-15.01 to 2.29	(-)	-0.61	0.08	0.08	(-)	40.35		
Passive ROM	-16.93 to 1.48	(-)	-0.14	0.69	0.69	(-)	42.73		
between rater A and rater C									
Active ROM	-0.7 to 13.13	(-)	-0.2	0.53	0.53	(-)	32.1		
Passive ROM	2.19 to 21.12	(+)	0.16	0.71	0.71	(-)	-		
between rater B and rater C									
Active ROM	4.5 to 20.74	(+)	0.36	0.21	0.21	(-)	-		
Passive ROM	13.44 to 25.33	(+)	0.2	0.33	0.33	(-)	-		
Intra-rater (within rater A)									
Active ROM	-8.69 to 5.31	(-)	-0.2	0.54	0.54	(-)	32.49		
Passive ROM	-8.45 to 6.2	(-)	0.39	0.21	0.21	(-)	34.01		

The first value of the three measurements of total range was used for calculation.

95%CI: 95% confidence interval for the mean difference; MDC95: 95% confidence interval of minimal detectable change; ROM: range of motion.

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