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## Original Research

## Proposal for a Method to Measure the Range of Dart-Throwing Motion

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**Purpose:** To examine the reliability of a novel technique to measure the range of the dart-throwing motion.**Methods:** Two raters measured the range of the dart-throwing motion in 40 healthy subjects. For the measurement, subjects were asked to perform a simulated hammering motion using various experimental tools (a real hammer, a thick wooden rod, and a thin wooden rod). The inclination angle of the tool in the vertical plane was measured with a manual goniometer at the maximal position of radial extension and ulnar flexion. The sum of these angles was defined as the range of the dart-throwing motion. To evaluate relative interrater reliability, intraclass correlation coefficients were calculated. To account for absolute reliability, Bland-Altman analysis was performed.**Results:** Intraclass correlation coefficients ranged 0.72 to 0.86. Bland-Altman analysis revealed that some systematic errors existed when the measurement was carried out with the real hammer or the thin rod, but not the thick rod. The 95% confidence intervals of minimal detectable change for the thick rod were 36.0° and 35.8° for the dominant and nondominant sides, respectively. Measured values between the experimental tools were similar.**Conclusions:** Relative reliability was shown to be good or moderate for each set of measurements. Some refinements are required to reduce measurement error. Accuracy of measurement should also be confirmed.**Clinical relevance:** No standardized methods for measuring the range of the dart-throwing motion have yet been established. Our technique can be performed rapidly and with easily available materials, producing reliable measurements for the range of the dart-throwing motion.Copyright © 2020, THE AUTHORS. Published by Elsevier Inc. on behalf of The American Society for Surgery of the Hand. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Wrist motion along the path from radial extension to ulnar flexion is called the dart-throwing motion (DTM); it is regarded as a kinematically natural and functional motion of the wrist joint.<sup>1</sup> Cadaveric studies<sup>2,3</sup> showed that the primary movement in DTM occurred in the midcarpal joint. A study<sup>4</sup> examining the temporal changes in radiographic findings of wrist bones and wrist joint dynamics after distal radial fractures demonstrated that mobility of the midcarpal joint was restored earlier than that of the radiocarpal joint; the range of DTM was fully restored at that time, whereas ranges of orthogonal anatomical

direction remained limited. These results showed that the range of DTM can indicate the mobility of the midcarpal joint in clinical practice. Meanwhile, studies<sup>5,6</sup> examining the relationships between the range of wrist motion and Disability of the Arm, Shoulder, and Hand (DASH) scores 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 describe disability in upper-limb disorders. These studies suggested that the range of DTM is a sensitive proxy for disabilities with respect to activities of daily living.

Although the range of DTM is a useful outcome measure in clinical settings, no standardized method to measure this motion has yet been established. This might be because no clinically useful, reliable, and easily available measurement methods have been developed. Kasubuchi et al<sup>7,8</sup> developed a dedicated device to measure the range of DTM and examined its reliability. Although

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Figure 1. Experimental tools.



Figure 2. Digital goniometer.

intra-rater and interrater reliability were good, the device was cumbersome compared with the conventional goniometer and impractical for clinical use. In 2013, Bugden<sup>9</sup> proposed a method using a conventional manual goniometer to measure DTM and mentioned that further research was needed to determine the reliability of the technique. Vardakastani et al<sup>10</sup> examined the reliability of a method for measuring the range of DTM that complied with Bugden's technique. In their report, goniometry was unable to quantify the range of DTM accurately. In our previous study,<sup>11</sup> which also evaluated the reliability of manual goniometry for measuring DTM, we reported that the manner of goniometer placement described by Bugden might be a cause of poor reliability, and that the setting for goniometer placement might have to be reviewed in future studies.

In this study, we propose a new method for measuring the range of DTM that does not rely on the subject's body for measurement axes. Furthermore, it is simple to use and employs easily available materials. The purpose of this study was to examine the reliability of our technique.

## Materials and Methods

### Participants

Forty healthy subjects (20 male and 20 female) with no history of orthopedic disease were included in this study. Mean age, height, and weight were  $19.7 \pm 1.6$  years (range, 18–25 years old),  $162.8 \pm 9.8$  cm (range, 147–182 cm), and  $56.6 \pm 14.3$  kg (range, 38–115 kg), respectively. A total of 37 subjects were right-handed and 3 were left-handed.

Two occupational therapists with more than 10 years of clinical experience served as raters. They received adequate explanation of the measurement procedure and practiced for about 1 hour to ensure mastery of skills before the experiment.

### Ethics

Before enrollment, subjects were given an information sheet; they gave written informed consent for participation. They were informed that participation was voluntary and they could withdraw at any time. Ethical approval for the study was granted by the research ethics committees of Shonan University (approval number 17-010).

### Study protocol

Range of DTM was measured by 2 raters on the same day. Measurement was performed using all 3 tools described subsequently for both the dominant and the nondominant sides. One trial was performed for a measurement of each set of experimental tools. The order of the tool and the sequence of the side to be measured were randomized for each subject. The order of the rater was also randomized. Intervals of 5 to 10 minutes were taken between examinations. Raters were not permitted to watch other raters measure subjects, nor did they have access to results.

### Instruments

A mallet, a thick wooden rod, and a thin wooden rod were used as experimental tools. The subject held each while performing the simulated hammering action during the measurement (Fig. 1). The mallet weighed 150 g and was 30 cm long. The center of gravity was located 21 cm distal from the proximal edge of the grip. The cross-sectional shape of the grip was rectangular with major and minor axes of 2.3 and 1.2 cm, respectively, with beveled corners. The thick and the thin rods were cylindrical. The cross-sectional diameters were 3.5 and 2.0 cm for the thick and thin rods, respectively. The thick rod was 30 cm long, weighing 200 g and the thin rod was 30 cm long, weighing 50 g. The center of gravity of the rods was at the midpoint of the length of the long axis. On the proximal edge of each tool, a 150-g bolt dangled from a 60-cm string.

A 200-mm-long digital goniometer (Shinwa Rules Co, Ltd, Tsu-bame, Niigata, Japan), weighing 162 g, demarcated in  $0.1^\circ$  increments, was used to measure angles (Fig. 2).

### Measurement of DTM

Subjects were seated on a chair. The forearm to be tested was placed on a table and held against the table by the subject's opposite hand to restrict motion of the elbow joint. Forearm position concerning pronation and supination was left up to the subject's discretion. The subject held the edge of the experimental tool and performed a hammering motion in the vertical direction. When holding the tool, the grasping position and finger posture were also left up to the subject's discretion. Once these were determined, the subject was not permitted to change the position or posture during each trial. The angle between the long axis of the tool and the horizontal plane was measured with the goniometer at the maximal position of radial extension and ulnar flexion. The attached string was used as the vertical reference (Fig. 3). The



**Figure 3.** Goniometer placement. The stationary arm of goniometer was aligned with the string and the movable arm was aligned with the long axis of the tool.

upward and downward motions beyond the horizontal plane were expressed as the positive angle for radial extension and ulnar flexion and were expressed as the negative angle when motion did not proceed beyond the horizontal plane. The sum of angles of radial extension and ulnar flexion was defined as the range of DTM (Fig. 4). The examiners were allowed to reduce the pendulum motion of the string manually during the measurement to save time.

At the orientation, the subject was instructed to hold the experimental tool firmly so that it did not move in the fist hand, to avoid forearm motion such as pronation or supination, and to perform the hammering action in the vertical direction. The subject was asked to practice the real action before the measurement until the examiner determined that the correct motion was learned.

#### Statistical analysis

Intraclass correlation coefficients ( $ICC_{2,1}$ ) were used to determine relative interrater reliability. The ICC was calculated for each tool for both the dominant and nondominant sides. Relative reliability was defined as poor (ICC less than 0.50), moderate (ICC 0.50–0.75), or good (ICC greater than 0.75) using previously established criteria.<sup>12</sup> To account for the absolute reliability between raters, the Bland-Altman method<sup>13</sup> was used. Calculations included 95% confidence intervals for the mean difference of the 2 paired measures, regression between the difference and the mean of the 2 paired measures, the standard error of measurement (SEM), the 95% confidence interval of minimal detectable change ( $MDC_{95}$ ), and the 95% limits of agreement (95% LOA). We calculated SEM using the equation:  $SEM = SD_d \times \sqrt{1 - \gamma}$ <sup>12,14</sup> ( $SD_d = SD$  of difference). The  $MDC_{95}$  was calculated using the equation:  $MDC_{95} = 1.96 \times SEM \times \sqrt{2}$ ,<sup>15</sup> and the 95% LOA was calculated using the equation:  $95\% LOA = \text{mean difference} \pm 1.96 \times SD_d$ .<sup>16</sup> When 0 did not lie within the 95% confidence interval for the mean difference of the 2 paired measures, fixed bias was considered to exist. When the regression between the difference and the mean of the 2 paired measures was significant, proportional bias was considered. The  $MDC_{95}$ , which is an indicator of reproducibility, can be used to define the smallest amount of change needed to be certain that a real change is occurring beyond a measurement error when there is no systematic error (fix bias or proportional bias). The 95% LOA can be used to define the range in which repeated measurement might be expected to vary with 95% confidence when there is a systematic error. The 95% LOA equation was used only for fixed bias; for the proportional bias, the variable of difference between 2 paired measures was replaced with its ratio to the mean of those measures. To analyze the effects of side (dominant vs nondominant),

tool, rater, and gender, 4-way repeated-measures analysis of variance was used.

#### Results

Table 1 lists descriptive statistics of measures for each rater. Table 2 shows the relative reliability of the measurement. Reliability of the DTM range was found to be good or moderate for each set of experimental tools. The reliability was good or moderate for the range of radial extension and ulnar flexion.

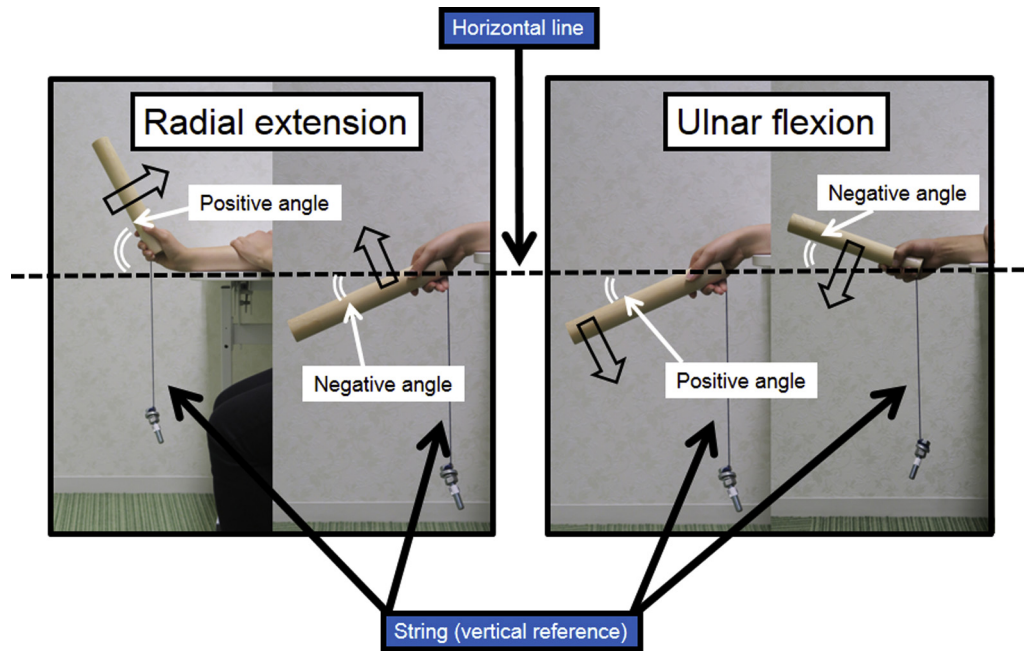
Bland-Altman analysis revealed that some systematic errors existed when the DTM range was measured using the hammer (both the fixed bias and the proportional bias) and the thin rod (fixed bias), but not the thick rod. Regarding the DTM range measured with the thick rod, the  $MDC_{95}$  was  $36.0^\circ$  and  $35.8^\circ$  for the dominant and nondominant sides, respectively (Table 3).

Four-way repeated-measures analysis of variance demonstrated that measured values between experimental tools ( $F_{1,938/73.632} = 2.923$ ;  $P = .62$ ), raters ( $F_{1/38} = 0.421$ ;  $P = .52$ ), and genders ( $F_{1/38} = 1.262$ ;  $P = .268$ ) were similar, whereas the effect of side was significant ( $F_{1/38} = 10.105$ ;  $P = .003$ ).

#### Discussion

There are 2 types of DTM<sup>17</sup>: one is called functional DTM and the other is pure DTM. The former is commonly performed in daily tasks, so this is regarded as DTM itself in a narrow sense. Functional DTM does not intercept the coronal and sagittal planes at the 0 position at the same time, meaning that the wrist does not take a neutral position during the motion, and the shape of its motion plane does not change (ie, to move rectilinearly). The hammering task is a representative motion of functional DTM.<sup>18–20</sup> The motion plane of pure DTM, performed only in particular situations such as experimental settings, passes the neutral wrist position. The goniometry technique proposed by Bugden<sup>9</sup> targeted functional DTM. The stationary arm and moveable arm of the goniometer were placed along the long axis of the radius and the shaft of second metacarpal, respectively, approximately  $45^\circ$  supinated from Lister tubercle. When the motion plane does not pass through the neutral wrist position, the direction of the longitudinal axis of the radius becomes nonparallel to the motion plane of the dart throw. This may have a negative impact on the reliability of Bugden's technique, because goniometer alignment becomes more difficult. Vardakastani et al<sup>10</sup> examined the reliability of a method to measure the range of DTM that conformed the method of Bugden; they reported that goniometry was unable 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 enabled the measurement to be used with confidence as part of a clinical assessment. We previously modified Bugden's technique to target pure DTM.<sup>11</sup> However, the reliability of the measured values was inadequate for clinical use. We believe that the poor reliability of the modified technique may have been caused by possible changes of direction or the shape of the motion plane in each subject, because pure DTM entails special intent and performance effort. Goniometer placement was also suspected to be a potential cause of poor reliability: When placing the stationary arm of the goniometer, it was difficult to identify the longitudinal axis of the radius visually because of the thick soft tissue covering this site. In the current study, considering all of these points, we offered a new manner that corresponds to functional DTM and does not rely on the subject's body for measurement axes.

This study showed that relative reliability was good or moderate for each tool. Bland-Altman analysis, however, revealed that some



**Figure 4.** In the measurement of radial extension, the upward motion beyond the horizontal plane was expressed as the positive angle. When the motion did not go beyond the horizontal plane, it was expressed as the negative angle. To the reverse, in measuring ulnar flexion, the downward motion beyond the horizontal plane was expressed as the positive angle. When the motion did not go beyond the horizontal plane, it was expressed as the negative angle. The sum of the angles of radial extension and ulnar flexion was defined as the range of DTM.

**Table 1**  
Results of Descriptive Statistics of Measures (degrees)\*

Variable	Hammer		Thick Rod		Thin Rod	
	Dominant	Nondominant	Dominant	Nondominant	Dominant	Nondominant
<b>Rater 1</b>						
Radial extension	88 ± 14 (34 to 108)	89 ± 16 (37 to 111)	87 ± 14 (33 to 107)	88 ± 13 (43 to 105)	87 ± 13 (41 to 106)	89 ± 13 (43 to 106)
Ulnar flexion	14 ± 16 (-15 to 45)	9 ± 16 (-20 to 48)	13 ± 16 (-12 to 42)	11 ± 15 (-10 to 50)	12 ± 18 (-28 to 51)	8 ± 18 (-17 to 68)
Total range (DTM range)	101 ± 17 (63 to 147)	98 ± 16 (69 to 134)	100 ± 19 (52 to 137)	100 ± 17 (60 to 134)	99 ± 17 (70 to 135)	97 ± 17 (63 to 141)
<b>Rater 2</b>						
Radial extension	84 ± 15 (33 to 109)	88 ± 15 (30 to 115)	85 ± 13 (35 to 109)	88 ± 13 (33 to 103)	85 ± 12 (49 to 107)	86 ± 13 (45 to 105)
Ulnar flexion	11 ± 20 (-20 to 56)	9 ± 20 (-26 to 55)	12 ± 15 (-11 to 45)	9 ± 15 (-15 to 44)	8 ± 17 (-17 to 53)	7 ± 19 (-21 to 48)
Total range (DTM range)	95 ± 22 (56 to 141)	97 ± 20 (53 to 147)	97 ± 18 (49 to 131)	97 ± 18 (60 to 141)	93 ± 16 (54 to 132)	93 ± 17 (56 to 133)

\* n = 40. Dominant indicates the value of the dominant hand; nondominant, the value of the nondominant hand. Values are mean ± SD (range).

**Table 2**  
Relative Reliability of Measurement\*

Variable	Hammer		Thick rod		Thin rod	
	Dominant	Nondominant	Dominant	Nondominant	Dominant	Nondominant
Radial extension	0.77 (0.58–0.88)	0.81 (0.67–0.89)	0.74 (0.56–0.85)	0.84 (0.72–0.91)	0.82 (0.68–0.90)	0.83 (0.64–0.91)
Ulnar flexion	0.81 (0.67–0.90)	0.77 (0.60–0.87)	0.86 (0.76–0.92)	0.81 (0.66–0.89)	0.82 (0.65–0.90)	0.82 (0.69–0.90)
Total range (DTM range)	0.73 (0.50–0.85)	0.79 (0.63–0.88)	0.72 (0.54–0.84)	0.76 (0.59–0.87)	0.74 (0.48–0.87)	0.76 (0.58–0.87)

\* Values are ICC<sub>2,1</sub> and associated 95% confidence intervals.

systematic errors persisted and the values of the MDC<sub>95</sub> were larger than acceptable for clinical applications. In general, reproducibility can be improved by repeating the measurement and averaging values. When the repeated measurements are conducted with a manual goniometer by one rater, it is difficult for the rater to avoid observer bias, because the rater is able to see the values during the second and subsequent trial. However, in our technique, repetitive measurement would be possible without observer bias by making modifications such as attaching an inclinometer directly to the tool rather than the string, so that the goniometer can be needless. Furthermore, random errors in the procedure of goniometer

placement can be eliminated, possibly resulting in decreased MDC<sub>95</sub>. Such modifications might be considered in future standardization processes.

In this study, measurement values were similar among experimental tools. This suggests that any objects considered to be applicable to hammering based on common sense might be used for our technique regardless of size, weight, shape, location of the center of gravity, or which side is to be tested. However, tools without systematic errors in measurements are likely to be more reliable, and this should be determined before standardization. When selecting the tool, it appears preferable to choose a

**Table 3**  
Bland-Altman Analysis for Interrater Values

Variable	95% Confidence Interval (degrees)	Fixed Bias	$\gamma$	P Value of $\gamma$	Proportional Bias	SEM (degrees)	MDC <sub>95</sub> (degrees)	95% LOA
<b>Hammer</b>								
Dominant side								
Radial extension	0.9 to 7.0	(+)	-0.16	.339	(-)	10.2	-	-14.7 to 22.6 (degree)
Ulnar flexion	-1.1 to 5.8	(-)	-0.36	.022	(+)	12.7	-	-429.1 to 525.0 (%)
Total range (DTM range)	2.0 to 10.6	(+)	-0.37	.018	(+)	15.7	-	-23.0 to 38.2 (%)
Nondominant side								
Radial extension	-1.3 to 4.7	(-)	0.08	.609	(-)	9	24.9	-
Ulnar flexion	-4.1 to 3.9	(-)	-0.36	.023	(+)	14.6	-	-487.7 to 559.1 (%)
Total range (DTM range)	-2.2 to 5.4	(-)	-0.31	.054	(-)	13.6	37.8	-
<b>Thick rod</b>								
Dominant side								
Radial extension	-1.8 to 4.4	(-)	0.06	.71	(-)	9.4	26.2	-
Ulnar flexion	-1.4 to 3.7	(-)	0.09	.578	(-)	7.6	21.1	-
Total range (DTM range)	-2.0 to 6.9	(-)	0.1	.557	(-)	13	36	-
Nondominant side								
Radial extension	-2.0 to 2.7	(-)	0.04	.824	(-)	7.3	20.2	-
Ulnar flexion	-1.0 to 5.0	(-)	-0.07	.66	(-)	9.7	26.8	-
Total range (DTM range)	-1.5 to 6.3	(-)	-0.14	.4	(-)	12.9	35.8	-
<b>Thin rod</b>								
Dominant side								
Radial extension	-0.8 to 4.1	(-)	0.09	.599	(-)	7.2	20.1	-
Ulnar flexion	1.3 to 7.7	(+)	0.11	.5	(-)	9.5	-	-15.3 to 24.2 (degree)
Total range (DTM range)	2.6 to 9.6	(+)	0.09	.586	(-)	10.4	-	-15.3 to 27.5 (degree)
Nondominant side								
Radial extension	1.3 to 5.7	(+)	0.03	.856	(-)	6.8	-	-10.0 to 17.1 (degree)
Ulnar flexion	-2.7 to 4.4	(-)	-0.04	.798	(-)	11.2	31.2	-
Total range (DTM range)	0.8 to 7.9	(+)	0.03	.865	(-)	11	-	-17.6 to 26.3 (degree)

95%CI = 95% confidence interval for the mean difference,  $\gamma$  = correlation coefficient between the difference and the mean of the two paired measures.

simple object that is readily available. Among the tools used in the current study, a cylindrical rod rather than a hammer would be preferable for this purpose. Furthermore, considering that some patients may have difficulty grasping owing to finger stiffness, as would be the case for patients after fractures of the distal radius, for example, a thick rod would be preferable to a thin one.

According to a study<sup>20</sup> that evaluated wrist kinematics during simulated hammering, the plane of DTM was found to be oriented an average of  $41^\circ \pm 3^\circ$  from the sagittal plane that was offset by  $36^\circ \pm 8^\circ$  in extension. Because we adopted a similar way to generate the DTM, we expected that the motion path of our technique would be similar to that of the previous study. However, the motion plane of wrist joint was not analyzed quantitatively in this study. Thus, there was no conclusive evidence that the motion was actually carried out in such a plane. In our technique, the forearm position of the subject in pronosupination was not standardized, which might have affected the reproducibility of the measures owing to the variety of motion directions. Moreover, we have no proof that wrist motion was performed vertically. If the motion plane was not vertical, our measures might have been geometrically different from the true range of the tool's motion. In addition, it is uncertain how firmly the tools were held without swinging in the hand. If the tool was not well-stabilized in the fist, there might have been a difference between the actual range of wrist motion and the recorded measures. In addition, the sample size was small for both the subjects and the raters; a larger series would be helpful to validate our findings. Furthermore, the use of radiographs and motion capture systems would prove valuable in assessing the accuracy of our methodology. The measurements of the range of radial extension and ulnar flexion are not regarded theoretically as true values because the kinematical  $0^\circ$  was not defined. Although the relative reliability was determined to be good or moderate for these motions, their accuracy has not yet been confirmed. Therefore, our technique should be applied only to the measurement of

total range of motion at this time. Finally, our measurement technique targeted only active range of motion.

Our technique is easy to perform with readily available materials. Further studies are required to verify its usefulness as a kinematic parameter or a surrogate end point in clinical settings, as well as to examine the accuracy of the measurement.

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