Original article

Underestimated active joint motions in patients with distal radius fractures: An observational study

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ABSTRACT

Purpose: Accumulating evidence indicates that underestimation of movements of the fractured hands leads to delayed recovery of motor function in patients with distal radius fractures (DRF). This study aimed to clarify the underestimated active range of motion (ROM) of a fractured hand in patients with DRF.

Subjects and Methods: This single-center, observational study included adult females with DRF or without fractures in the upper limbs and hands. They were divided into the following three groups: (1) DRF, (2) healthy and unrestricted ROM, and (3) healthy and limited ROM with jigs. All participants estimated ROM of the wrist and forearm joints at the fracture side based on that at the healthy side. Analysis of covariance was used to determine differences among the three groups. Outcome measures were differences between actual and self-conjectural ROM.

Results: The subjective ROM degrees of DRF patients were -20° for volar flexion, -21° for dorsal flexion, -31° for pronation, and -24° for supination, which were lower than those of Non-fracture participants. Significant differences between subjectively estimated and actual ROM degrees among groups in wrist joint volar flexion ($\chi^2 = 26.01, p < 0.01$), dorsal flexion ($\chi^2 = 24.00, p < 0.01$), pronation ($\chi^2 = 14.10, p < 0.01$), and supination ($\chi^2 = 15.19, p < 0.01$) were observed.

Conclusions: This study indicates that self-conjectural ROM of injured joints is underestimated in patients with DRF. Our findings suggest that active movements should be encouraged in DRF patients with modest hand use.

Key words: Distal radius fracture, Rehabilitation, Self-conjecture, ADL, Range of motion

INTRODUCTION

Distal radius fracture (DRF) is a common fracture that occurs more often in females than in males (Larsen, 1993). DRFs are mostly caused by sports and traffic accidents in young people and falls from a standing position in older people (Nellans, 2012; Macintyre, 2016). The risk of DRF in active people who go out at least once a day is 3.2 times higher than that in people who rarely work outdoors (Hagino, 2004); fractures of other bones, especially hip fractures, are more likely to occur after DRF, and the overall relative hazard is 1.54 for females and 2.3 for males (Malmin, 1993). Accordingly, it can be expected that most of the patients with

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DRF in rehabilitation are eager to return to normal life because they are active before the injury.

During DRF treatment, arthrodesis takes 7–10 days, and resting fixation or restriction of motion for 6 weeks is performed by conservative therapy (Ikpeze, 2016). After the joint fixation in the fracture treatment is completed, rehabilitation such as exercise therapy begins (Ikpeze, 2016). Accumulating studies have indicated that exercise therapy is effective for pain and range of motion (ROM) (Burder, 2017); ROM and grip strength improve in approximately 6 weeks after exercise therapy, but recovery of activities of daily living (ADL) takes 3–6 months (Burder, 2017; Osada, 2008). In patients with fractures, including the wrist-joint fracture, it takes 6 months for health-related quality of life to recover to premorbid levels (Hagino, 2009), and more than 40% of the patients have difficulty with ADL, even 1 year after injury (Macdermid, 2003). However, patients with DRF often underestimate the recovery of motor function (Björk, 2020). For example, in a previous survey that estimated the degree of ADL recovery in patients with DRF 3 months after the operation and at the start of rehabilitation, 45% of the patients reported that they had less than 70% recovery; patients' grip strength, ROM, and ADL had low recovery at 3 months after surgery (Björk, 2020). Moreover, in patients with surgically treated DRF, those with low self-esteem had a 6-fold increased risk of residual moderate or severe pain after 1 year compared with those without low self-esteem (Busse, 2019).

False self-awareness, especially underestimation, is associated with low self-efficacy. Maximova et al. reported that children with overweight or obese status tended to underestimate their body size when compared with those with normal weight. Maximova et al. reported that children with underestimated recognition of their body size had higher self-efficacy than adults with accurate recognition of their body size (Maximova, 2015). Duncan et al. conducted a survey in obese adults and found that 30% (risk rate) misrecognized their body size compared with adults who recognized their body size correctly and 40% attempted to lose weight 1 year before the survey (Duncan, 2011). Duncan et al. suggested that those who underestimated their body size or function did not try to optimize their body size.

Previous studies have suggested that patients with DRF often underestimated future self-abilities and suppressed joint movement and hand use in ADL, failed to maximize their joint capacity, and had delayed functional recovery because they underestimated their joint function. This phenomenon, if occurring in patients with DRF, should be considered in the treatment program for recovery of hand function. Cognitive-behavioral therapy for obesity involves providing interventions to correct awareness of own body. Marzoni et al. reported that cognitive-behavioral therapy using virtual reality (Riva, 2011) to correct the body's self-recognition led to the maintenance of weight loss (47.8%), compared with the normal cognitive-behavioral therapy alone (28.9%) and usual weight loss program (10.3%) with follow-up of 12 months (Marzoni, 2016). Fractures are pathologically different from obesity; if patients with DRF underestimate their physical function, interventions that promote accurate recognition can be helpful. However, we have not found any reports investigating the underestimation of the active ROM in patients with DRF. Therefore, this study aimed to test the hypothesis that patients with DRF underestimated the ROM of their wrist joints. If patients with DRF underestimate their wrist function, interventions to correct them may be considered.

Subjects and Methods

1. Participants

The survey was conducted between 2013 and 2020. This study was approved by the Ethics Committee of the Saitama Prefectural University (no. 25512) and the Ethics Committee of the Kitasato University Medical Center (no. 26-3). Informed consent was obtained from all patients for study participation, and written consent was obtained from all patients. This study included female outpatients and inpatients with DRF and those without upper limb dysfunction (non-DRF) at the Kitasato University Medical Center. This study only included female patients because DRF occurs more often in females than in males (Larsen, 1993). Patients with DRF who received volar locking plate fixation and conservative therapy were recruited.

The eligibility criteria for patients with DRF were females who underwent surgery and received conservative therapy after a fracture, while those for patients without DRF were females with no upper limb dysfunction. Patients who did not want to participate in both groups and those aged 18 years or younger were excluded. In addition, patients with DRF and large soft tissue damage other than fractures, fractures due to tumors, history of diseases affecting upper limb function such as rheumatism and neurological disorders, or dementia or history of mental illness were excluded. No therapeutic intervention was administered to the patients in this study.

2. Technical assessments

The following items were investigated to determine whether patients underestimated their ROM: age, handedness, fracture severity (Arbeitsgemeinschaft für Osteosynthesefragen classification), active ROM, and the maximum ROM that patients estimated at the affected side compared with the intact side. Participants were divided into the following three groups: DRF group (participants with a fractured wrist joint), non-DRF_{Free} group (participants without fracture who had free movement of the wrist joint), and non-$DRF_{Restraint}$ group (participants without fracture whose ROM of the wrist joint was restricted to the average value of the DRF group).

Sensory receptors in the muscle spindle and joint capsule are stretched to help detect joint position and sense joint angles (Sachs, 1992). The firing rate of the sensory nerve is proportional to stimulation intensity, and it is known that sensory nerve firing is more frequent during increased joint angle (Mountcastle, 1966). Because joint angles in patients with fractures were more restrained than those in individuals without fractures, we speculate that the firing rate of the sensory nerves affected the joint position sense. Therefore, we set a condition (non-$DRF_{Restraint}$ group) that limited the ROM to the equivalent range in the DRF group. A jig was used to restrict the joint angle of the non-$DRF_{Restraint}$ group with reference to the wrist joint angle of the DRF group. The ROM (i.e., volar flexion, dorsal flexion, pronation, and supination) was measured using a goniometer.

Figure 1 shows the main outcome indicators. As for the estimated ROM of the affected side, the wrist joint of the affected side was naturally rested on an armrest, eyes were closed, and the patient was asked to estimate and report the ratio of the self-estimated ROM between the affected side and the intact side.

The measurement procedure was as follows: First, the maximum active ROM of each joint was measured by the examiner, and the maximum active ROM was estimated by the patients immediately after they experienced it. Wrist joint angles were restricted using a jig in the non-$DRF_{Restraint}$ group. Restricted angles using a jig were based on the average ROM in the DRF group. The non-DRF restraint group

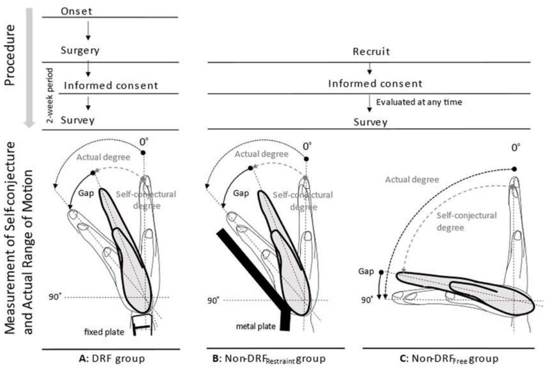

Figure 1: Study procedure and description figures of self-estimated degrees of range of motions.

The non-DRF$_{Restraint}$ group was recruited after data collection for the non-DRF$_{Free}$ group. The DRF group was investigated within 2 weeks after admission for rehabilitation. Measurements in the non-DRF$_{Free}$ and non-DRF$_{Restraint}$ groups were performed on any day after informed consent was provided for study participation. The maximum ROM of each joint was measured by an examiner, and participants also self-estimated the maximum ROM immediately after they experienced it. The wrist joint angle was restricted by a jig in the non-DRF$_{Restraint}$ group. Angle limitation by a jig was set at an average degree of ROM measured in the DRF group. Measurements in the non-DRF$_{Restraint}$ group were performed immediately after participants experienced jig-limited angles for volar flexion, dorsal flexion, pronation, and supination. The hands in the non-DRF$_{Free}$ group and non-DRF$_{Restraint}$ group were ipsilateral to the affected side in the DRF group.

also experienced active ROM in a restricted state using jigs. Measurements in the non-DRF$_{Restraint}$ group were performed immediately after the participants experienced jig-limited angles for volar flexion, dorsal flexion, pronation, and supination. The hands in the non-DRF$_{Free}$ and non-DRF$_{Restraint}$ groups were ipsilateral to the affected side in the DRF group. (The measurements in the non-DRF group and non-DRF$_{Restraint}$ group were performed by setting the left and right sides of the virtual fracture hand according to the DRF group.)

Second, an examiner verbally conveyed instructions to the patient: (1) “Please rest your hands on an armrest and close your eyes.” (2) “How much does an affected side move when the move of an intact hand is classified as 100%? Please guess exactly about it” (Figure 1). Third, the estimated angle of the affected side was calculated using Equation 1. Finally, the differences between the actual and self-estimated ROM (gap; volar flexion, dorsal flexion, pronation, and supination) at the affected side were assessed using Equation 2.

$$\text{Self estimated ROM at an affected side} = \frac{x}{100} \times \text{ROM at an intact side} \qquad \text{Equation 1}$$

$$\text{Differences between actual and self estimated ROM at an affected side} = \text{Self estimated ROM at an affected side} - \text{Actual ROM at an intact side} \qquad \text{Equation 2}$$

Where x indicates the patient’s self-reported conjectural angle ratio compared with the intact side.

Figure 2 shows the posture and jig at the time of the measurement. The hands in the non-DRF$_{Free}$ and non-DRF$_{Restraint}$ groups were ipsilateral to the affected side in the DRF group. Examinations were performed within 2 weeks of the start of rehabilitation in the DRF group. Assessments were performed in the non-DRF$_{Free}$ and non-DRF$_{Restraint}$ groups on any day after informed consent was obtained.

3. Statistical analyses

The study sample included 37 cases, and the main outcome was the function of the wrist joint (Michigan hand outcomes questionnaire) based on a previous study (Shirzadi, 2020), with an effect size = 0.25, α level = 0.05, and ideal power = 80%. G*power was used for sample size calculation (Faul, 2007). The primary outcome was the difference between the self-estimated

Figure 2: Setting of a participant's position.

Positions of a patient included sitting, shoulder flexion and 0° abduction, and 90° elbow joint. The wrist joints at a predicted side in the $DRF_{Restraint}$ group were restricted by a metal plate and were jig-fixed prior to volar flexion and dorsal flexion. During supination and supination, they were restricted using a jig with a wood panel.

and actual ROM. Levene's test was used for the homoscedasticity test of all data sets, and the normality assessment was performed using the Shapiro-Wilk test. The generalized linear model (GLM) was used to determine the group difference in the gap between the self-estimated and actual ROM among the DRF, non-DRF_{Free}, and non-$DRF_{Restraint}$ groups. Coefficient of determination (R^2) was used for the goodness-of-fit test. Accumulating evidence indicates that aging might be a factor associated with altered sensory receptors and impaired self-estimation of ROM (Aydoğ, 2006), and ROM is affected by a high body mass index (BMI) score (Jeong, 2018). Therefore, age and BMI were used as covariates. The missing values of data were substituted by the median values of the measured indexes, and the analysis result in those cases was the same as that before substitution. Jamovi (The jamovi project, 2021) (Ver.1.2) was used for data analysis, and the significance level was set at 0.05.

RESULTS

Figure 3 shows the participant recruitment flow and the examination process. A total of 123 patients were recruited in this study: 77 in the DRF group and 46 in the non-DRF group. Of the 77 patients in the DRF group, 17 (22.0%) were excluded because their homes were too far from the hospital, 21 (27.2%) had dementia and mental illness, 11 (14.2%) had fractures due to tumors or other illnesses, and 2 (2.5%) refused to participate in this study. As a result, 24 patients with DRF completed the survey. A total of 46 participants without DRF were recruited after examinations in the DRF group were completed. In the non-DRF groups, 39 participants who met the eligibility criteria completed the survey.

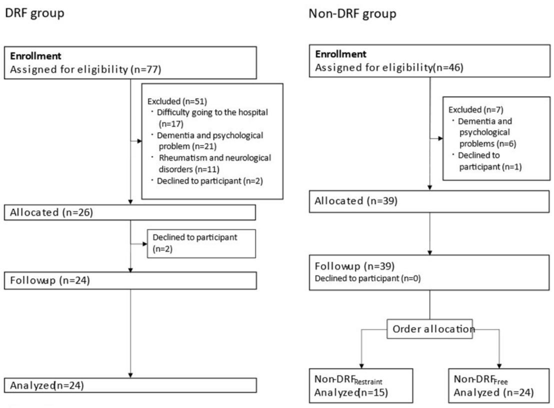

Figure 3: Study design and recruitment flow of participants in the trial.

Table 1 shows the characteristics of the participants. Seven patients had missing BMI values, which were substituted by the median value calculated based on the available BMI data of each group. The mean age (mean ± SD) of the participants was 66 ± 7 years in the DRF group, 67 ± 12 years in the non-$DRF_{Restraint}$ group, and 67 ± 13 years in the non-DRF_{free} group. The duration from the day of injury to the day of admission was 17 ± 12 days in the DRF group. No differences were found in baseline patient

Table 1: Characteristics of participants

Characteristics		Groups			Statistics		
		DRF (n = 24)	Non-$DRF_{Restraint}$ (n = 15)	Non-DRF_{Free} (n = 24)	df	*p* values	ε^2
Age, mean ± SD		66 ± 7	67 ± 12	67 ± 13	2	0.82	< 0.01
Body mass index		23 ± 5	24 ± 4	25 ± 4	2	0.18	0.05
Side	Dominant hand, right	22	15	22	2	0.52	0.02
	Dominant hand, left	2	0	2			
	Conjectured hand, right	12	11	17	2	0.53	0.02
	Conjectured hand, left	12	4	7			
ROM, intact side	Wrist joint, volar flexion	71 ± 8	73 ± 7	70 ± 7	2	0.51	0.02
	Wrist joint, dorsal flexion	72 ± 10	75 ± 7	75 ± 9	2	0.50	0.02
	Forearm, pronation	90 ± 1	90 ± 0	90 ± 0	2	0.44	0.02
	Forearm, supination	90 ± 2	90 ± 0	90 ± 0	2	0.44	0.02
ROM, conjectured side	Wrist joint, volar flexion	38 ± 11	73 ± 7	72 ± 8	2	< 0.01	0.71
	Wrist joint, dorsal flexion	36 ± 17	74 ± 7	74 ± 7	2	< 0.01	0.67
	Forearm, pronation	57 ± 28	90 ± 0	90 ± 1	2	< 0.01	0.74
	Forearm, supination	60 ± 22	90 ± 0	90 ± 0	2	< 0.01	0.77
Treatments	Surgical fixing	20	-	-	-	-	-
	Conservative therapy	4	-	-	-	-	-
Arbeitsgemeinschaft für Osteosynthesefragen (AO) classification	Extra-articular (A)	5	-	-	-	-	-
	Partially articular (B)	6	-	-	-	-	-
	Complete articular (C)	13	-	-	-	-	-

Data are shown as mean ± standard deviation. Statistics was performed by one-way ANOVA. Missing data of body mass index in 7 participants (DRF group, 4; non-DRF free group , 1; non-DRF restraint group, 2) were substituted by the median value of each group. To reduce the effect of laterality, the measured side of the non-DRF restraint group and non-DRF free group was set ipsilateral to the affected side in the DRF group. DRF group consists of 12 right hand fractures and 12 left hand fractures.

characteristics among the three groups, except for ROM at the affected side (Table 1). In the normality assessment by Levene's test, the measured differences between self-estimated and actual ROM data were confirmed for volar flexion (F = 1.64, p = 0.20) and dorsal flexion (F = 2.05, p = 0.13) in the wrist joint, but not for pronation (F = 19.6, p < 0.01) and supination (F = 12.1, p < 0.01) in the forearm. The main effects of groups were examined using GLM for the gap and degrees of volar flexion, dorsal flexion, pronation, and supination. Significant model fits by groups were found in the gap differences between self-estimated and actual values in volar flexion based on the GLM (R^2 = 0.33, AIC = 530, χ^2 = 26.01, p < 0.01). The DRF group had lower self-estimated values (median, 25th and 75th percentiles; -20 [-28, -11]°) than the non-$DRF_{Restraint}$ (14 [-3, 18]°, z = -4.77, p < 0.01) and non-DRF_{Free} (0 [-10, 4]°, z = -3.65, p < 0.01) groups based on post-hoc multiple comparisons. In addition, dorsal flexion was model fitted by groups (R^2 = 0.31, AIC = 533, χ^2 = 24.00, p < 0.01), and the DRF group had significantly lower self-estimated ROM (-21 [-30, -9]°) than the non-$DRF_{Restraint}$ (-1 [-13, 17]°, z = -4.56, p < 0.01) and non-DRF_{Free} (0 [-6, 5]°, z = -4.63, p < 0.01) groups. Moreover, pronation was model fitted by groups (R^2 = 0.21, AIC = 577, χ^2 = 14.10, p < 0.01), and self-estimated ROM was significantly lower in the DRF group (-31 [-42, 2]°) than in the non-$DRF_{Restraint}$ (-12 [-19, 6]°, z = -2.75, p = 0.02) and non-DRF_{Free} (0 [0, 0]°, z = -3.65, p < 0.01) groups. Furthermore, supination was model fitted by groups (R^2 = 0.23, AIC = 576, χ^2 = 15.19, p < 0.01), and the DRF group had significantly lower self-estimated ROM (-24 [-43, -4]°) than the non-$DRF_{Restraint}$ (-15 [-29, 2]°, z = -2.11, p = 0.105) and non-DRF_{Free} (0 [0, 0]°, z = -1.08, p < 0.01) groups.

DISCUSSION

In this study, we found that the subjective ROM degrees of patients with DRF (-20° for volar flexion, -21° for dorsal flexion, -31° for pronation, and -24° for supination) were significantly lower than those of participants without DRF, and the self-estimated ROM at the fracture side was lower in the DRF group than in

Table 2: Comparisons of the gap between self-conjuctural and actual range of motions among groups.

Directions	df	Groups						Goodness-of-Fit			
		DRF (n = 24)		Non-DRF$_{Restraint}$ (n = 15)		Non-DRF$_{Free}$ (n = 24)		R^2	AIC	χ^2	*P* values
VF_Actual	2	40	34, 45	75	70, 78	70	69, 80	0.81	455	248	< .001
DF_Actual	2	38	25, 50	75	73, 80	75	70, 80	0.72	197	148	< .001
Pronation_Actual	2	58	40, 80	90	90, 90	90	90, 90	0.47	548	51	< .001
Supination_Actual	2	55	40, 80	90	90, 90	90	90, 90	0.57	512	77	< .001
VF_Conjectual	2	20	12, 30	51	35, 55	70	67, 79	0.71	525	141	< .001
DF_Conjectual	2	8	3, 22	35	23, 53	75	69, 80	0.72	536	261	< .001
Pronation_Conjectual	2	27	4, 50	45	38, 63	90	90, 90	0.57	578	76	< .001
Supination_Conjectual	2	27	4, 60	45	32, 59	90	90, 90	0.60	572	84	< .001
VF_Gap	2	-20	-28, -11	14	-3, 18	0	-10, 4	0.33	530	26	< .001
DF_Gap	2	-21	-30, -9	-1	-13, 17	0	-6, 5	0.32	533	24	< .001
Pronation_Gap	2	-31	-42, 2	-12	-19, 6	0	0, 0	0.21	577	14	< .001
Supination_Gap	2	-24	-43, -4	-15	-29, 2	0	0, 0	0.23	577	15	< .001

Statistics was performed by GLM (model type, linear; distribution, Gaussian). Data are shown as median, 25th and 75th percentile. ROM, range of motion; VF, volar flexion; DF, dorsal flexion; Gap, differences between the actual and self-estimated range of motion; DRF, distal radius fracture; AIC, Akaike's information criterion; Actual, degree of active range of motion conjectured side; Conjectural, estimated angle of the affected side was calculated using Equation 1; Gap, differences between the actual and self-estimated ROM using Equation 2.

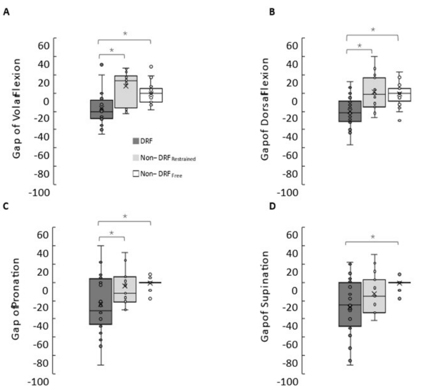

Figure 4. Gap between actual and self-conjectured range of motion degrees. Comparisons among the following groups: A, volar flexion; B, dorsal flexion; C, pronation; and D, supination. Boxplots show the median, 25th percentile, and 75th percentile. Generalized linear model and post-hoc multiple comparisons were used to determine the group differences. *The significance level was set at 0.05.

the non-DRF group. Consistently, in a previous study, 45% of the patients self-estimated that their recovery would be 70% or less on the day of admission, and patients with DRF and low self-estimation recovery had low grip power, ROM, and ADL recovery values at 3 months after surgery (Björk, 2020). The underestimated ROM is one of the targets to be corrected by rehabilitation because the self-esteem on physical and life functions is correlated with prognosis in patients in convalescence after a fracture. The self-estimation method of ROM and its estimated values in this study may provide some references for patients to judge whether they should receive correction by rehabilitation.

No difference was found between the actual and self-estimated ROM of forearm supination in the DRF and non-DRF$_{Restraint}$ groups. This result might be explained by the fact that the origin and attachment areas of the affected muscles were around the elbow joint, supinator and biceps, supinator, and brachioradialis (Neumann, 2017). In addition, Jeong et al. revealed that obese patients who had different soft tissues in the upper extremity had different ROMs between pronation and supination (Jeong, 2018). Therefore, the self-estimated ROM of forearm supination is presumed to be less susceptible to DRF.

Björk et al. reported that the recovery of forearm supination function was affected by low self-efficacy (Björk, 2020). However, it is unclear why self-efficacy affects supination. The outcome of Björk et al. was patient's self-efficacy for normal activity 3 months after fracture. A previous study found that supination 0–50° was required in washing one's face

(Morrey, 1981). Supination can be compensated by shoulder abduction and internal rotation, although supination is difficult to compensate by the shoulder joint. Therefore, the effect on ADL is greater in the supination than in the pronation. This should be considered, as the under-estimation of the ROM within 2 weeks after surgery is different from the normal activity after 3 months.

One of the factors that cause an under-estimation of ROM is the decreased activity of motor image-related areas in the brain after joint fixation in patients with DRF. For example, Héroux et al. demonstrated a significant difference in cerebral cortex activities between the injured and intact sides, and the cerebrum was affected in patients with orthopedic disease who had a history of unilateral knee anterior cruciate ligament injury, as demonstrated using resting potentials in the motor cortex (Héroux, 2006). In addition, Langer et al. showed that the thickness of the motor-sensory cortex was reduced, and diffusion index fractional anisotropy, which indicates nerve connectivity, was decreased in 10 patients with upper limb orthopedic disease with fixed hands (Langer, 2012). Moreover, Burianová et al. measured the cerebral blood flow by functional magnetic resonance imaging in 16 healthy young people after their fingers were fixed for 24 h and found a decrease in region synchronization and a significant increase in the resting motor threshold in transcranial magnetic stimulation (Burianová, 2016). Another reason why patients underestimate their ROMs is that joint fixation required during the DRF treatment reduces the motor function in a short period and leads to decreased cerebral blood flow after 24-h joint fixation (Burianová, 2016) and reduced thickness of the motor cortex 16 days after DRF injury (Langer, 2012). Given that these changes in brain activities and structures alter joint perception in patients with DRF, rehabilitation should be considered to modify joint position sense. In the present study, the average duration from injury to the start of rehabilitation was of 17 ± 12 days, suggesting a decrease in cerebral cortex activities as noted in previous studies (Langer 2012).

Psychological factors associated with underestimated ROM may include depression, fear of pain, and anxiety in patients with DRF. A previous study showed that 25% of patients with DRF were depressed, and functional recovery after 1 year was lower in patients with depression (Modarresi, 2019). In addition, Imai et al. found that patients with postoperative DRF who had a high fear of pain (pain catastrophe scale) hesitated to perform finger movements and showed slow movement and amplitude phenomenon in the finger-tapping tasks (Imai, 2018). Consistently, another study demonstrated that patients with chronic pain restricted joint movements when their pain was unpredictable (Meulders, 2019). Therefore, patients with DRF might have anxiety and depression due to pain caused by DRF and/or surgery. However, the psychological states of anxiety and depression in patients were not examined in this study. In patients with DRF, anxiety and depression might affect the self-underestimation of ROM; thus, further studies are needed to elucidate the effects of anxiety and depression, and the related results should be helpful for treatment and rehabil-itation.

This study has several limitations. First, it was unclear whether ROMs were also self-underestimated in younger adults and males with DRF. This study was conducted at a single institution and targeted only females in their 50s to 80s. Notably, recovery of dexterity after DRF is affected by age and sex (Bobos, 2018; Bobos, 2018), and motor imagery is also affected by age and sex (Subirats, 2018; Mulder, 2003). Therefore, further multicenter studies are needed to clarify the effects of age and sex.

Second, patient's passive ROM could not be measured in this study because the patients were in a fixed phase of post-fracture treatment, and their passive movements were still restricted by their physicians. We also did not investigate hypoesthesia or hyperesthesia. The sensory function and passive ROM of the patients who underestimated their ROM might be affected by sensorimotor deficits after a distal radius fracture. For example, Adachi et al. reported that patients with a low number of sensory receptors in the remnant membrane had false joint position sense among those who underwent reconstruction of the anterior cruciate ligament (Adachi, 2002). Therefore, further multicenter studies are needed to clarify the effects of sensory and passive ROM. Third, this was an observational study; thus, it remains unclear whether modifying self-estimated ROM could improve functional recovery and increase the frequency of hand use in patients with DRF. Third, this study did not investigate the psychological state of patients with DRF, such as anxiety and depression. Patients' motor function and hand use in daily life can be restored in short periods. Hence, further corrective intervention studies are needed to determine the effects of motor function and hand use on psychological indicators.

In conclusion, this study found self-underestimation of ROM in patients with DRF. The finding suggests that ROM should be examined in clinical rehabilitation. Given that self-underestimated ROM is caused by sensory impairment, brain function changes, and psychological status in patients with DRF, motor imagery and sensory stimulation should be considered to prevent changes in brain function and structures.

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