

Strength Required for Opening Plastic Bottles in Individuals with Distal Radius Fracture

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Abstract

To estimate the hand function required to open a plastic bottle, we aimed to find out which factors are involved and to determine the cutoff value over the course of conservative therapy in patients with a distal radius fracture. In this case control study, outpatients who visited a single hospital and a single orthopedic surgery clinic were included. Fifty patients each were included in the open group (those able to open a plastic bottle) and non-open group (those unable to open a plastic bottle). Using a torque meter, the torque value required to open a plastic bottle was measured. We also examined the association between grip strength and pinch strength. We examined the function of the hand between two groups: an open group and non-open group. The period after injury (odds ratio [OR] 1.07, 0.02), pain (OR 1.68, $p=0.018$), grip strength of the affected hand (OR 1.50, $p=0.001$), pinch strength of the affected hand (OR 1.12, $p=0.001$), and torque value (OR 1.74, $p=0.001$) were identified in logistic regression analysis as predictive factors for the openness of a plastic bottle. The receiver operating characteristic curve showed the cutoff values of the affected hand for predicting the ability to open a plastic bottle in terms of the period after injury (28.5 days), pain (1.53), e grip strength of the affected hand (20.5 kg), pinch strength of the affected hand (4.5 kg), and torque value (95 N-cm). We found that three factors are significantly involved in the ability of a patient with a distal radius fracture to open a plastic bottle, and it was possible to obtain a cutoff value for each factor. These values are suggested to be goals in promoting rehabilitation.

Keywords: Distal radius fracture; Rehabilitation; Injuries; Orthopedic surgery; Articular rheumatism; Spinal injury

Introduction

Lateral pinch strength is commonly used to open a container lid or bag of food and access the contents [1,2]. Tasks such as opening daily commodities, food containers, and drug packaging bags are difficult for patients with motor disorders, including fracture of the wrist joint or finger and tendon injuries; patients with diseases, including stroke, articular rheumatism, and spinal injury; or the elderly because of muscle strength loss or other reasons [1,2]. A report by Bodur et al. [3] evaluated the ability of elderly people living in a community to open food, measured the time taken to open packs, and assessed the time between the grip and pinch strength. The opening of seven kinds of food was difficult, and the strength of the hand was related to the successful opening of the water bottle and biscuit pack; the function of the hand was the most important factor in determining the opening property. This shows that the function of the hand is the most important factor in determining whether a person can open a container, but its cutoff value is unknown.

In Japan, Yamabe et al. [4] reported the activities of daily living (ADL) of 28 patients with distal radius fracture; of 28 motions, opening a plastic bottle lid was difficult or impossible for 25/28 subjects (89%) and wringing out a rag was difficult or impossible for 20/28 subjects (71%). Thus, opening a plastic bottle lid was deemed as the most difficult motion to perform. According to Saito et al. [5], of four daily commodities (plastic bottle, jelly, pudding, and snack food packaging bags), the greatest force required to open commodities was

exerted in opening a plastic bottle. Opening such daily commodities commonly requires lateral pinch strength. In clinical settings, the use of daily commodities is permitted based on the recovery phase of the patient after the measurement of grip strength and pinch strength [6] and consultation with physicians. However, few reports have reported the use of numerical indicators as criteria [7]. Rajkumar et al. examined the relationship among grasping force, pinch strength, and ADL of patients with leprosy, and they found a very significant correlation between grip and pinch strength, and ADL. One report suggested that there is a significant relationship among these factors during this period [8]. For this reason, it is expected that the measurement of grip strength and pinch force will be an important factor in predicting ADL.

In Japan, it is important to predict the feasibility of performing ADL in individuals with fractures of the distal end of the radius, which is more common among women in their 50s and 60s. Since the cutoff value of hand function, which is the most important factor for determining the degree of opening a container, is unknown, setting a target value is considered necessary for advancing rehabilitation.

Therefore, to estimate the hand function required to open a plastic bottle, we aimed to find out which factors are involved and to determine the cutoff value over the course of conservative therapy in patients with a distal radius fracture.

Methods

Subjects

The subjects comprised patients who received closed treatment and rehabilitation therapy for right distal radius fracture at the Fuchinobe General Hospital and Kihara Orthopedic Clinic between November 2012 and November 2015 and for whom the use of the affected hand in daily life was allowed by physicians. One hundred patients were investigated, and patients with sensory disturbance or surgical history of the affected hand were excluded. We also excluded patients with concomitant ipsilateral injuries (ulnar styloid fractures, scaphoid injuries, and complex regional pain syndrome). Based on the AO Classification of Fractures [9], the subjects were divided into three groups: 35 patients without displacement and 55 (A2) and 10 (B1) patients with displacement who achieved joint stability following closed reduction. All subjects (23 men and 107 women; mean age 61.5 ± 13.9 years) were right-handed. The study was registered with the University Hospital Medical Information Network (registration number UMIN-CTR: UMIN000025310). This study was conducted after approval from the Ethics Committee of Fuchinobe General Hospital was obtained (approval number: 09-007). Participants gave written and verbal informed consent. All procedures were performed in accordance with the ethical standards of the Institutional and National Ethics Compliance Committees, and the Declaration of Helsinki of 1975, as revised in 2008.

Method and tools for measurement

The strength needed to open a plastic bottle was measured with a torque meter (Digital Torque Meter 2TME450CN; Tohnichi Mfg. Co., Ltd.), according to the Japanese Industrial Standards [9]. The measurement range of the torque meter is 0.90-450 N-cm (Figure 1), digitally. Lateral pinch strength was measured using the Pinch Gauge (B&L Engineering Mechanical Pinch Gauges PG-30; Division of Pinsco, Inc. [0-30 pounds/0-13.5 kg reading]), and grip strength was measured at the second position (the second narrowest width) using the Jamar Grip Strength Dynamometer (B&L Engineering Hand dynamometer, Division of Pinsco, Inc. [0-200 pounds/0-90 kg reading]). Furthermore, the pain level was determined at the time of the measurement using the visual analog scale (VAS) and range of motion (ROM) (forearm pronation-supination and wrist flexion-extension). The evaluations were performed by one occupational therapist with 20 years of experience.



Figure 1: The equipment used and measurement position. Digital Torque Meter 2TME450CN (N-cm), c, Co., Ltd.

Experiment Procedures

The plastic bottle used in this study had a lid diameter of 28 mm and was able to hold 500 mL, which is a common size in Japan; additionally, it is a brand manufactured in large quantities (ITO EN, Ltd.). The measured task was the opening of a plastic bottle immobilized on the torque meter, using the dominant hand. After demonstrating the measurement method, we allowed participants to practice opening the bottle several times, and then we obtained the measurements once they understood the task. A new plastic bottle that had never been opened was used. All subjects were those who verbally confirmed that they were able to open a plastic bottle using the injured side before the injury. After demonstrating the measurement method, we allowed the participants to practice opening the bottle several times, and then we obtained the measurements once they understood the task. The opening motion was described to the patients as follows: hold the lid with a lateral pinch and open it slowly. After practicing several times using an already opened bottle, the measurement was conducted using an unopened bottle. The measurement of muscle strength was obtained after receiving permission from the doctor after cast removal. In addition, use of the affected hand in everyday life was started once the doctor and therapist permitted it. We began conducting measurements after cast removal when the patient was cleared by the doctor for grip strength and pinch force measurements, and specific ADL. The subjects were classified into two groups: those who fully unscrewed the lid of a plastic bottle (open group) and those who did not (non-open group). The measurement was conducted in the seated position. The torque device used in this study is a device that can read the maximum value. For this reason, we set the maximum value during opening of the plastic bottle as the opening torque value. In accordance with the American Society of Hand Therapists (ASHT) third edition, lateral pinch strength and grip strength at the second position were measured in the seated position with the shoulder adducted, elbow flexed to 90 degrees, forearm neutral, and wrist positioned at 15-30 degrees of extension and 0-15 degrees of ulnar deviation. A rest period of at least 15 seconds was provided between repetitions. Between the muscle force measurements, a break of 15 seconds or more was set according to the measurement of ASHT. The measurement was conducted once by the affected hand and once by the unaffected hand.

Statistical Analysis

- 1) The chi-square test was used to analyze sex; otherwise, the unpaired t-test was used for all analyses in both the open and non-open groups.
- 2) Pearson's correlation coefficient was used to determine the relationship between torque value and grip strength and pinch strength in both the open and non-open groups.
- 3) A logistic regression model was used, with the ability to open a plastic bottle as the target variable and measurement time and each item of muscle strength as explanatory variables. Based on the calculated predictive factors regarding opening daily commodities, the threshold and the precision of differentiation to predict that a plastic bottle would be opened were examined. We obtained a receiver operating characteristic (ROC) curve for the predictors extracted from the logistic regression and calculated an area under the curve (AUC) of the ROC curve. Sensitivity and specificity were calculated using the assessment of the ROC curve. The cutoff value was defined at the maximum sum of the sensitivity and specificity.

SPSS version 11.5j (IBM Corp.) was used for statistical analysis. Statistical significance was set at $p < 0.05$.

Results

We examined function of the hand between the two groups. Analysis with an unpaired t-test found significant differences between the open group and non-open group in terms of the period after injury ($p=0.02$), pain ($p=0.03$), grip strength of the affected hand ($p=0.004$), pinch strength of the affected hand ($p=0.002$), and torque value ($p=0.02$) (Table 1).

In the open group, the torque value of a significant correlation was observed between the two groups for the grip strength of the affected hand and pinch strength of the affected hand ($r=0.81$, $r=0.75$; $p < 0.01$). In the non-open group, the grip strength of the affected hand, grip strength of the non-affected hand, and pinch strength of the affected hand were significantly correlated between the two groups ($r=0.73$, $p < 0.05$; $r=0.53$, $p < 0.01$; $r=0.68$, $p < 0.01$, respectively).

There was a significant correlation between the period, pain, affected side grip strength, and affected side knob force in the open group and non-open group (Table 2).

Table 3 shows the results of logistic regression analysis. The period after injury (odds ratio [OR] 1.07, 95% confidence interval [CI] 0.78-1.36, $p=0.03$), pain (OR 1.68, 95% CI 1.10-2.54, $p=0.02$), grip strength of the right hand (OR 1.50, 95% CI 1.26-1.91, $p=0.001$), pinch strength of the right hand (OR 1.12, 95% CI 0.88-1.29, $p=0.001$), and torque value (OR 1.74, 95% CI 1.04-2.91, $p=0.001$) were identified as predictive factors for opening the plastic bottle. Based on the ROC curve, the cutoff value for the predictive factors for bottle opening were as follows: the period after injury (28.5 days; sensitivity 89.3; specificity 93.0; AUC 95.2; $p=0.001$); pain (1.53; sensitivity 94.8; specificity 88.6; AUC 96.8; $p=0.001$); grip strength of the right hand (20.5 kg; sensitivity 86.6; specificity 94.4; AUC 96.4; $p=0.001$); pinch strength of the right hand (4.5 kg; sensitivity 91.1; specificity 94.4; AUC 96.3; $p=0.001$); and torque value (95 N-cm; sensitivity 96.4; specificity 83.3; AUC 98.7; $p=0.001$) (Table 4).

	Open group Mean (SD) (n=50)	Non-open group Mean (SD) (n=50)	χ^2 , F	p-value
Male/Female	17/33	18/32	0	0.83
Age: years	60.1 (13.5)	62.1 (14.7)	1.2	0.55
Period after injury: Day of illness (days)	76.9 (30.4)	28.3 (20.9)	2.1	0.02*
Pain: VAS (cm)	0.4 (0.8)	2.3 (1.1)	1.9	0.03*
ROM forearm (degree)	130.2 (25.6)	117.5 (23.7)	1.2	0.59
ROM wrist (degree)	108.2 (19.7)	104.9 (15.3)	1.7	0.08
Grip strength of the affected hand (kg)	23.7 (5.6)	8.3 (3.7)	2.3	0.004**
Grip strength of the non-affected hand (kg)	35.7 (12.9)	26.6 (11.7)	1.2	0.49
Pinch strength of the affected hand (kg)	5.7 (1.4)	2.3 (0.9)	2.4	0.002**
Pinch strength of the non-affected hand (kg)	7.0 (2.2)	5.8 (2.2)	1	1
Torque value (N-cm)	104.4 (8.8)	37.8 (12.4)	2	0.02*

Note: Sex was analyzed using the chi-square test; otherwise, the unpaired t-test was used. * $p < 0.05$, ** $p < 0.01$. ROM: Range of Motion; VAS: Visual Analog Scale.

Table 1: Exposure among strength and torque cases (open group) and controls (non-open group).

	Torque value							
	Age	Age	Period	Pain	Forearm	Wrist	Affect grip	Non-affect grip
Open group N=50	-0.23	0.28	0.08	0.69**	-0.31	0.44	0.24	0.47**
Age								
Period after injury								
Pain								
ROM forearm								
ROM wrist								
Grip strength of the affected hand								
Grip strength of the non-affected hand								

	Pinch strength of the affected hand	0.75**	-0.51*	0.55**	-0.49*	0.07	0.07	0.52**	0.50*	Affect pinch
	Pinch strength of the non-affected hand	0.2	-0.52*	0.07	-0.33	0.46	0.46	0.27	0.46	0.43
		Torque value								
Non open group N=50	Age	-0.04	Age							
	Period after injury	0.25	0.39*	Period						
	Pain	-0.51	-0.2	0.55**	Pain					
	ROM forearm	0.32	-0.4	0.36	-0.31	Forearm				
	ROM wrist	0.15	-0.2	0.23	-0.22	-0.44	Wrist			
	Grip strength of the affected hand	0.73**	-0.5	0.56*	-0.52**	-0.24	-0.2	Affect grip		
	Grip strength of the non-affected hand	0.53*	0.07	-0.12	-0.22	-0.54	-0.5	0.06	Non-affect grip	
	Pinch strength of the affected hand	0.68**	-0.5	0.49*	-0.46*	0.07	0.07	0.75**	0.28	Affect pinch
	Pinch strength of the non-affected hand	0.15	0	-0.28	-0.37	-0.46	-0.5	-0.2	0.51*	0.15
Note: Pearson's correlation coefficient. *p<0.05, **p<0.01.										

Table 2: Correlations among the open group and non-open group.

Factor	Odds ratio	95% CI	p-value
Period after injury	1.07	0.78-1.36	0.03*
Pain	1.68	1.10-2.54	0.02*
Grip strength of the right hand	1.5	1.26-1.91	0.001**
Pinch strength of the right hand	1.12	0.88-1.29	0.001**
Torque value	1.74	1.04-2.91	0.001**
Note: CI: confidence interval. *p=0.05, **p=0.01. ORs and CIs are provided according to logistic distribution.			

Table 3: Factors for predicting the possibility that a subject could open the plastic bottle.

Factor	Cut-off	AUC, %	p-value	Sensitivity, %	Specificity, %
Period after injury	47.5	95.2	0.001	89.3	93
Pain	1.53	96.8	0.001	94.8	88.6
Grip strength of the right hand	20.5 kg	96.4	0.001	86.6	94.4
Pinch strength of the right hand	4.5 kg	96.3	0.001	91.1	94.4
Torque value	95 N*cm	98.7	0.001	96.4	83.3
Note: AUC: area under the curve. **p<0.01.					

Table 4: Cutoff value, AUC, sensitivity, and specificity of each factor.

Discussion

Regarding the opening of a plastic bottle, the criteria and method for opening packages and containers are specified in the Japanese Industrial Standards as a design guideline with consideration for the elderly and disabled persons, and the torque values required for opening these items are described [10].

According to the Japan Food Packaging Association, the torque value for opening a plastic bottle should be approximately 100 N-cm [6]. In the open group of our study, the mean torque value was approximately 105 N-cm, which is similar to the value recommended by the association. In the comparison of the two groups, there was a significant difference in the period after injury, pain, affected side grip strength, and affected side pinch strength (Table 1). In addition, the correlation was also high for pain, affected side grip strength, affected side pinch strength, and torque value (Table 2). These findings suggest that these factors represent the function of the hand opening a plastic bottle. The period, pain, grip strength, and pinching force may be indicators of the goal of rehabilitation, if the cutoff values are obtained.

Fractures were classified into the inflammatory phase, reparative phase, and remodeling phase by Rockwood et al. [11]. Additionally, it has been reported that it takes 4-12 weeks until the bone fracture is joined by a callus and ready to withstand some exercise load. In the non-open group, we considered that bone union was not achieved since subjects felt pain, which is likely because callus formation was insufficient.

According to Villar et al. [12], the grip strength decreases by about 35% when the radial shortening exceeds 5 mm in patients with distal radial fracture. Solgaard [13] reported that patients complain of instability and tenderness at the distal radioulnar joint. In this study, morphological factors were not considered, but morphological factors were considered for factors that affect hand functions.

Furthermore, in our study, we investigated the muscle strength sufficient for opening a plastic bottle and examined the cutoff value. Based on the assessment of the ROC curve, a high precision of differentiation to predict this possibility was shown by the period after injury of 47.5 days, VAS score of 1.53 cm, grip strength of 20.5 kg, and pinch strength of 4.5 kg, both in the right hand. Nalebuff and Phillips assert that about 9 kg 20 of grip and about 2.3-3.2 kg of pinch force are adequate for most ADL [14].

In the present study, there was also a significant difference between the period from injury and pain, suggesting a relationship with the ability to exert. Moreover, no significant difference was noted in terms of ROM of the forearm or wrist joint. When evaluating the measurement items again with pain and ROM, the period from injury and pain were significant. Grip strength of the affected hand, pinch strength of the affected hand, and torque value were significantly different between the two groups. Although there was no significant difference in the ROM of the forearm and wrist joint, the findings suggested that the period from onset and pain are significantly involved in exercising power. Patient's strength will improve with progressive resistance movement by gradually using weight to improve the muscle strength that was affected. Additionally, on a daily basis, we encourage patients to write letters and turn doorknobs, or we recommend that they use the affected side to perform light domestic activities.

It was considered that these cutoff values may be a goal for patients. For patients who cannot achieve these values, it is important to

recommend self-help devices that are specific for opening a plastic bottle. Since there are several types of self-help devices, including devices for gripping or pinching, these improve the frequency of using the hand. We plan to examine the cutoff value of patients with other diseases and sensory disturbance and determine whether it is possible to open a plastic bottle with a lower torque value through a study on self-help devices.

Limitations

In this study, the subjects only had distal radius fracture and patients with sensory disturbance were excluded. The measurement was conducted once in the affected hand and once in the unaffected hand. Therefore, our findings may not be applicable to patients with other diseases and sensory disturbances. In this study, we could not limit the use of strength of the upper arm to help with bottle opening. We would like to see issues with standardization in various diseases of elderly people addressed using statistical methods based on multivariate analysis and modeling by a detailed evaluation using three-dimensional analysis.

Conclusions

In the present study, patients with distal radius fracture were asked to unscrew the lid of a plastic bottle, and the results showed a torque value similar to the standard value for the opening of plastic bottles stipulated by the Japan Food Packaging Association.

A period after injury of 28.5 days or more, pain of 1.53 or more, grip strength of 20.5 kg or more, and pinch strength of 4.5 kg or more seemed sufficient for the opening of a plastic bottle.

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