Measurement of Rehabilitation in Thumb MP Joint Subluxation due to Rheumatoid Arthritis

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***Abstract*— As treatment for subluxation due to rheumatoid arthritis (RA), rehabilitation by hand therapy is one option, but the number of therapist is not sufficient. Therefore, a device for rehabilitation of thumb metacarpophalangeal (MP) joint subluxation has been developed. To improve the device, it is necessary to measure in close proximity to the actual rehabilitation. Therefore, the authors tried to measure two kinds of rehabilitation by using motion capture and a contact force sensor. To measure rehabilitation movements, three markers were attached to the metacarpal bone, six markers were attached to each side of the interphalangeal (IP) joint, MP joint and proximal phalanx of the right thumb of the subjects, and a finger model was created by these markers. Further, three markers were placed on the left index of the therapist, and force direction was calculated by these markers. Measurement was conducted on healthy subjects, Rehabilitation was performed by the person who is not a therapist, but received the guidance of the doctor who is coauthor. As a result, the authors could measure rehabilitation by hand therapy, force, point of action and displacement. The results suggest that rehabilitation with traction twice as efficient as that without traction. Furthermore, it was found that rehabilitation is possible with calculated force, and the force is reproducible by the actuator in the device.**

I. Introduction

Rheumatoid arthritis (RA) patients in Japan number about 800,000 [1]. Roughly 80-90% of RA patients develop it in the hands and wrist [2], resulting in the dislocation and deformation of the finger. Drug treatment, operative therapy and rehabilitation by hand therapy exist at treatment options. Hand therapy involves the lowest risk, but the number of therapist is not sufficient.

Thus, a device using a membrane-type pneumatic actuator for rehabilitation of thumb metacarpophalangeal (MP) joint subluxation due to RA was developed. Using the device, treatment was successful in four out of five RA patients [3].

To improve the device and success rate, it is necessary to measure in close proximity to the actual rehabilitation. Therefore, we tried to measure two kinds of rehabilitation therapies, one with traction, and one without. Then, we investigated the difference between the two types and whether rehabilitation is possible with the calculated force. In this study, rehabilitation by hand therapy was measured with a motion capture system, and the force of the therapist was measured by contact force sensor.

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II. Rehabilitation in Thumb MP Joint Subluxation

A. Subluxation and rehabilitation by hand therapy

Subluxation is a dislocation in which two bones are in partial contact as shown in Fig. 1. In rehabilitation of MP joint volar subluxation, the therapist adds moment, which pushes up the proximal phalanx to the dorsal and returns the bone to the normal position. In some cases, the rehabilitation is done with traction, which pulls the bone.

B. Dynamic rehabilitation assist device

Figure 2 shows the device for rehabilitation. This device is composed of an air compressor, pressure controller, finger fixture and pneumatic actuator. This actuator expands with supplied compressed air and pushes up the proximal phalanx. In a previous study, the force generated by the actuator was approximated by

$$F = \pi p r^2 , \tag{1}$$

where F is maximum generated force, p is supplied pressure, and r is radius of actuator [4].

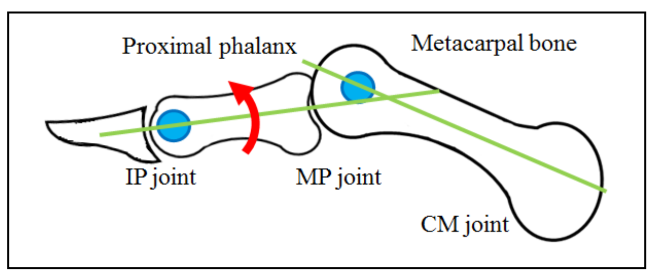


Figure 1. MP joint volar subluxation

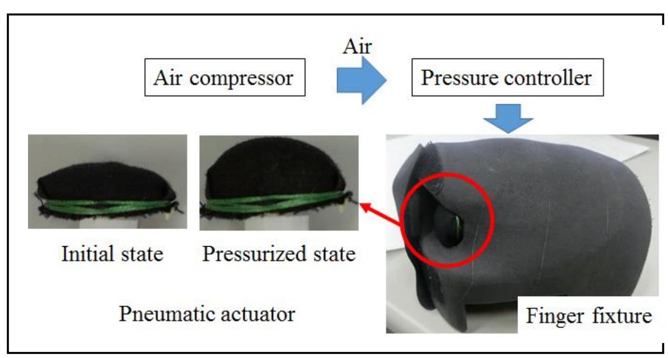
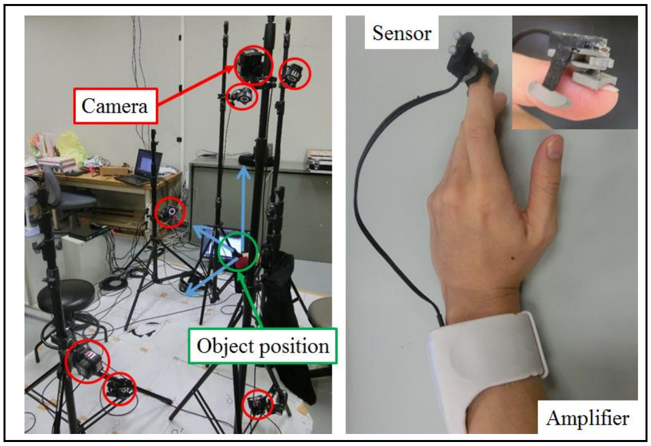


Figure 2. Dynamic rehabilitation assist device prototype for RA



(a) Position of cameras (b) Position of sensor

Figure 3. Measurement device

III. EXPERIMENT ON MEASURING REHABILITATION

A. Measurement device

The motion capture system VENUS3D (Nobby Tech., Japan) was used to measure rehabilitation; it has seven cameras, and Fig. 3(a) shows their positions. This system is optical and needs markers to measure.

The contact force sensor HapLog (Tec Gihan, Japan) was used to measure the force of the therapist, and was worn as shown in Fig. 3(b). This sensor estimated force by measuring the mechanical deformation of the side of the fingerpad [5]. Using this sensor, it is possible to measured force until 30 (N).

B. Position of markers and finger model

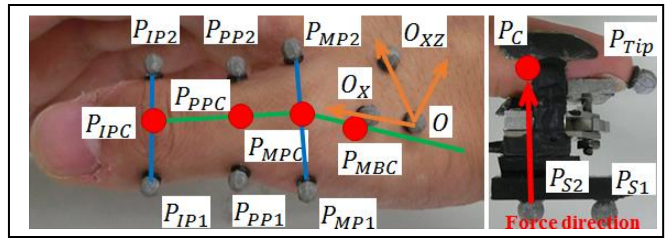
Markers 4 mm in diameter were attached to the subjects and therapist with an aqueous adhesive. Position of markers in consideration of the error by skin movement was suggested [6]. Because the position was limited because of hands crossing, however, the authors ignored the error and attached markers as follow.

Nine markers were attached to the subjects, and Fig. 4(a) shows their positions. Three (O, O_x and O_{xz}) were attached to the dorsal of the metacarpal bone of the right thumb, and one each was attached to the radial and ulnar sides of the metacarpal bone of the MP joint (P_{MP1} and P_{MP2}), the proximal phalanx of the interphalangeal (IP) joint (P_{IP1} and P_{IP2}), and middle of the proximal phalanx (P_{PP1} and P_{PP2}).

A finger model was made using these markers. First, the centers of the MP joint (P_{MPC}) and IP joint (P_{IPC}) and P_{PPC} are calculated as the midpoints between markers on both sides. Second, the point on the axis of the metacarpal bone (P_{MBC}) is calculated as

$$\boldsymbol{P}_{MBC} = \boldsymbol{O} + \boldsymbol{O}_x \boldsymbol{P}_{MPC}, \tag{2}$$

This finger model is composed of the axis of the proximal phalanx ($P_{IPC}P_{PPC}$) and the metacarpal bone ($P_{MPC}P_{MBC}$), of the MP joint ($P_{MP1}P_{MP2}$) and IP joint ($P_{IP1}P_{IP2}$), and the centers of the MP joint (P_{MPC}) and IP joint (P_{IPC}). The coordinate system of the model is that in which O is the origin, O_x is on the x-axis and O_{xz} is on the xz-plane.



(a) Subject (b) Therapist

Figure 4. Position of markers and finger model

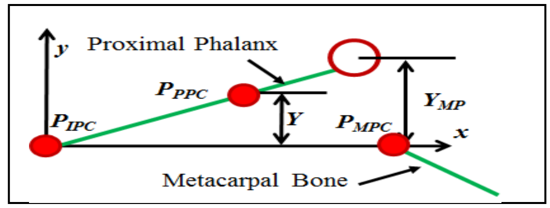


Figure 5. Displacement of the proximal phalanx

Next, three markers were attached to the therapist, and Fig. 4(b) shows their positions. One (P_{Tip}) was attached to the left index finger-tip, and two (P_{S1} and P_{S2}) were attached to the sensor worn on the left index finger. However, P_{S2} needed to be attached above the finger pad that generated force.

Force direction was calculated by using these markers. First, contact force was assumed to be parallel to the axis of the bone and perpendicular to the finger pad surface. By using this assumption, a point (P_C) was calculated as

$$x = \frac{a_3(a_3-a_2)^2 + (a_3-a_2)\{(b_3-b_1)(b_3-b_2)+(c_3-c_1)(c_3-c_2)\} + a_1\{(b_3-b_2)^2+(c_3-c_2)^2\}}{(a_3-a_2)^2+(b_3-b_2)^2+(c_3-c_2)^2}, \tag{3}$$

where x is x-coordination of P_C, and y- or z-coordination was calculated by changing a into b, b into c and c into a, or a into c, b into a and c into b. Thus, force direction is calculated by vector $P_{S2}P_C$.

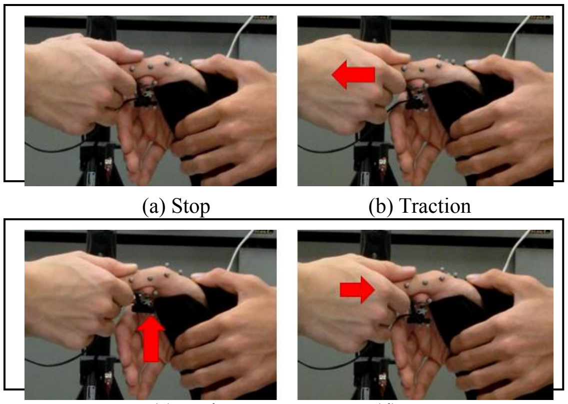
C. Calculating point of action and displacement

First, we describe how to calculate point of action on the proximal phalanx. This point was calculated as the intersection of the axis of the proximal phalanx ($P_{IPC}P_{PPC}$) and the plane including force direction ($P_{S2}P_C$).

Second, we describe how to calculate displacement of the proximal phalanx. To calculate this, the coordinate system is that in which P_{IPC} is the origin, P_{MPC} is on the x-axis and P_{IP1} and P_{IP2} are on the xz-plane. The displacement is the y-coordinate of the P_{PPC}, but this is dependent on the positions of P_{PP1} and P_{PP2}. Thus, the displacement Y was converted into the displacement Y_{MP} in the MP joint as shown in Fig. 5.

D. Experiment method

In this study, the subjects were 14 healthy men (21-26 years old), and the rehabilitation was the action of pushing up from the normal position to the side of the dorsal, and performed by the person who is not a therapist, but received the guidance of the doctor who is coauthor. Further, we divided the rehabilitation into four actions as follow: (i) The stop step (three seconds, Fig. 6(a)) is the step in which the therapist pinches the thumb IP joint with his right thumb and


(a) Stop (b) Traction

(c) Push (d) Return

Figure 6. Rehabilitation

index finger, and the left index finger of the therapist is below the proximal phalanx of the subject. (ii) The traction step (three seconds, Fig. 6(b)) is the step in which the therapist pulls the proximal phalanx of the subject with his right thumb and index finger and maintains this condition until (iv). (iii) The push step (six seconds, Fig. 6(c)) is the step in which the therapist pushes the proximal phalanx of the subject with his left index finger. (iv) The return step (three seconds, Fig. 6(d)) is the step in which the therapist returns to the proximal phalanx of the subject. This cycle composed of (i)-(iv) is rehabilitation with traction. The other rehabilitation is the cycle that changes (ii) into (i) and (iv) into (i).

In this study, we measured five cycles of two rehabilitations for each subject using a motion capture system and contact force sensor. In this measurement, the sampling rate of the motion capture cameras and sensor was 200 Hz.

IV. Results and Discussion

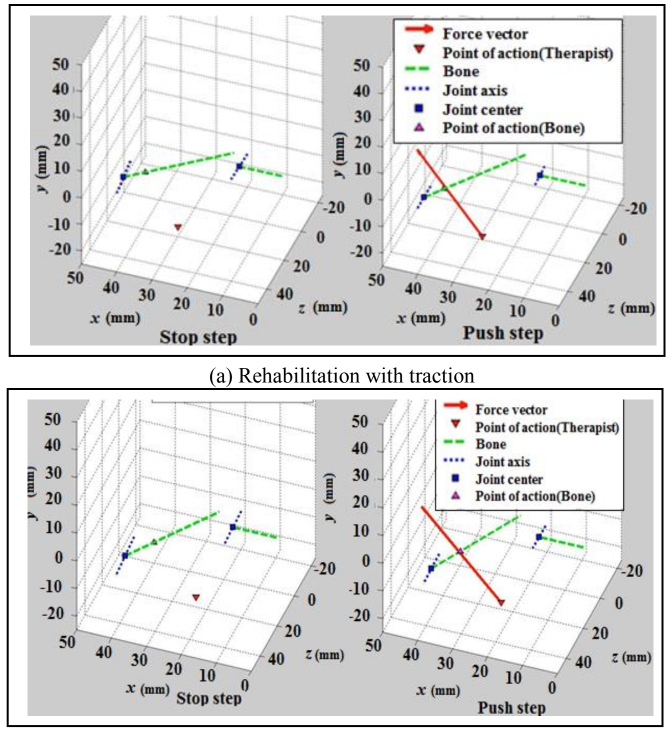
Figure 7 shows the rehabilitation measured, and (a) is rehabilitation with traction and (b) is that without traction. The left side of Fig. 7 is the stop step and the right side is the push step. As can be seen from the figure, it was measured that the MP joint side of the proximal phalanx was pushed up, and contact force was generated. In the following, we describe the point of action, force, and displacement of the proximal phalanx.

A. Measured point of action

Figure 8 shows the points of action of all subjects in two kinds of rehabilitations. These values were expressed as the position of the point of action from the IP joint based on the length of the proximal phalanx. In this study, these were averaged for all subjects to determine the position of the actuator on the device. In the result, both mean values are 0.34 (standard deviance (SD) = 0.10 in rehabilitation with traction, and SD = 0.12 in the other rehabilitation). Thus, it seems that 0.34 is the position of the actuator on the device in this study.

B. Measured force

Figure 9(a) shows the force of one subject in two kinds of rehabilitations. First, it is found that the maximum force of each of the five cycles is approximately equal as shown in Fig. 9(a), but the force between subjects is different. Second, the force was converted into force in point of action 0.34 measured above (rehabilitation force) to compare the maximum force between two rehabilitations. As a result, the maximum force of all subjects is shown in Fig. 9(b), whose horizontal axis is force of rehabilitation without traction and whose vertical axis is that of rehabilitation with traction. As shown in Fig. 9(b), it is found that rehabilitation force with traction is approximately 70% of that without traction (R^2 = 0.89, and SD = 3.5). Therefore, rehabilitation with traction is better; however, the displacement of the proximal phalanx



(a) Rehabilitation with traction

(b) Rehabilitation without traction

Figure 7. Measured rehabilitation

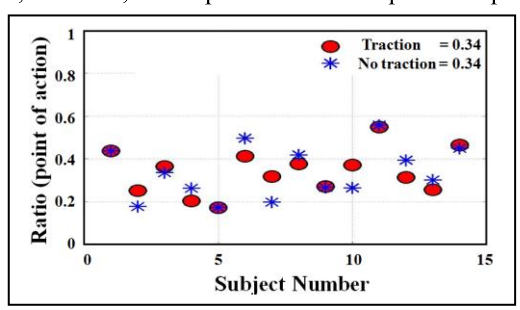
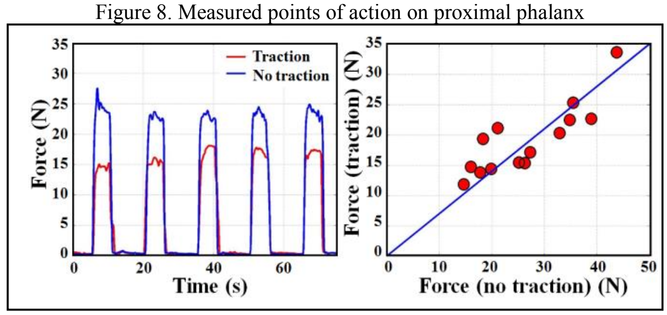
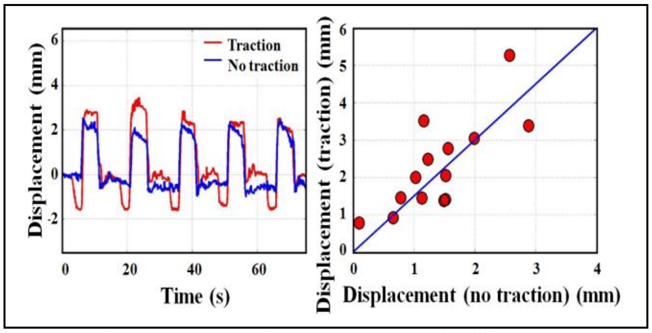


Figure 8. Measured points of action on proximal phalanx



(a) Force of one subject (b) Relationships between two rehabilitations

Figure 9. Measured force



(a) Displacement of one subject (b) Relationships between two rehabilitations

Figure 10. Measured displacement of proximal phalanx

may be small.

C. Measured displacement of proximal phalanx

Figure 10(a) shows the displacement of the proximal phalanx in the two kinds of rehabilitations measured. It is found that the maximum displacement of each of the five cycles is approximately equal as shown in Fig. 10(a), but the displacement between subjects is different. Further, it is found that the displacement of the rehabilitation with traction is changed in the traction and return steps. Thus, considering only the displacement pushing up, maximum displacement is calculated to compare the displacement between the two rehabilitations. Figure 10(b) shows the maximum displacement as does Fig. 9(b). As shown in Fig. 10(b), the displacement of rehabilitation with traction is approximately 1.5 times larger than that without traction ($R^2 = 0.82$, and $SD = 0.83$). Therefore, rehabilitation with traction is better, as well as rehabilitation force, and the efficiency of rehabilitation is twice as high. For this reason, a device that can perform rehabilitation with traction should be developed.

In addition, considering that force required and displacement were different between all subjects, it may be evaluated the flaccidity of the MP joint using these two values. If we can evaluate it, it is possible to control the force by the actuator on the device in accordance with the symptoms of RA patients.

D. Rehabilitation force

In this study, because the measurement was carried out on healthy subjects, we examined whether rehabilitation using the measured rehabilitation force is possible. In a previous study, treatment using the device was successful in 50 kPa < p < 100 kPa for three RA patients and p < 50 kPa for one RA patient [3].

Thus, we assume rehabilitation using rehabilitation force is possible when rehabilitation force is larger than the force generated at 50 kPa (lower limit force: F_{MIN}). Further, the force generated by the device is calculated by (1), whose r is 9.85 mm and converted into the force in point of action 0.34 for each subject to compare with rehabilitation force. The lower limit force of rehabilitation with traction is supposed to be 70% of F_{MIN}. Figure 11 shows the result of whether rehabilitation using the measured rehabilitation force is possible. Here, F_{MAX} is higher limit force, which is the

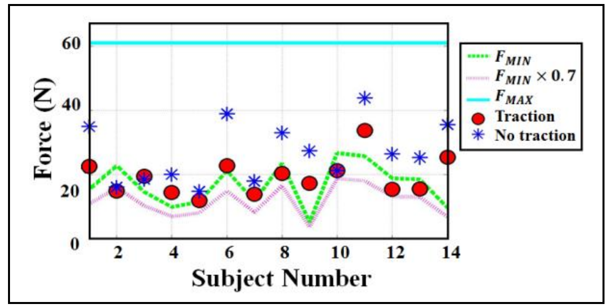


Figure 11. Rehabilitation force and the range

maximum force reproduced by the actuator (p=200 kPa) on the device. As shown in Fig. 11, all subjects are within the range in rehabilitation with traction, and 12 out of 14 subjects are within the range in the rehabilitation without traction. Two out of 14 subjects are out of range, but it seems that this is within allowance because one out of five RA patients was successful in lower than 50 kPa in the previous study. Thus, it seems that rehabilitation using the measured rehabilitation force is possible, and the force is reproduced by the actuator on the device.

V. Conclusion

In this study, we proposed a method of measuring rehabilitation by hand therapy using motion capture and contact force sensor; and force, point of action and displacement were measured using this method. By using this measurement values, it was found that the efficiency of rehabilitation with traction was double that without traction. Further, using rehabilitation force measured for healthy subjects, we determined that rehabilitation is possible, and the force is reproduced by the membrane actuator on the device. In future study, the same experiment as this paper must be performed by therapist and RA patients to confirm whether this method is useful for patients and obtain the data.

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