人間工学的体内力源能動義肢手部の開発・研究

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抄録
本研究は，体内力源能動義肢の手部の開発を目的としたものである。能動義肢手部の開発・研究に先立ち，1）市販の能動義肢手部の問題点を探るための力学的検討，2）人における掴み動作時の拇指運動分析の検討，を行った。
1）においては，微細な運動を制御するために非常な困難を伴うことが認められた。また，2）においては，手先部拇指の撓側外転と掌側外転の中間位への運動が必要なことを確認した。
以上の結果から，新しいタイプの能動義肢手部を開発し，これを随意開閉式手部と称した。

キーワード：体内力源能動義肢手部，随意開大手部，随意閉鎖手部，動作分析，３次元分析，筋電図

Introduction

Rehabilitation engineers have successfully cooperated with medical rehabilitation teams in improving the quality of life of the physically disabled through their welfare-related products, most outstandingly,prostheses and braces.

Another example of cooperation, is the development of an externally-powered upper-extremity prosthesis. Although there are many skillfully made prostheses, the upper extremity amputee patients rarely use them. Dr.Suzuki reports that such equipment, designed by researchers to suit their tastes, do not measure up to the real needs of the upper-extremity amputee patients.

In order to develop an internally powered functional prosthetic hand that amputee patients can use easily, we analyzed by electromyogram the upper-extremity muscular movement of grasping. We studied how the upper-extremity proximal muscular movement changes as the wrist joint moves, as well as heeded our attention to thumb movements that compensate for a fixed wrist joint. We simultaneously checked the grasping movement and later dynamically analyzed a commercialized internally-powered functional prosthetic hand. We used a three-dimensional video (3D) to analyze grasping action.

As a result of this research series, we developed an internally-powered functional prosthetic hand testing piece.

Method

1. Dynamic analysis of the functional prosthetic hand.

We measured the traction power with the control-cable of the internally-powered functional prosthetic hand, the distance between the thumb and the index finger and between the thumb and the index and middle fingers, and the change of pinch power.

The ten kinds of internally-powered functional prosthetic hands consist of nine kinds of voluntary opening hands and a voluntary closing hand.

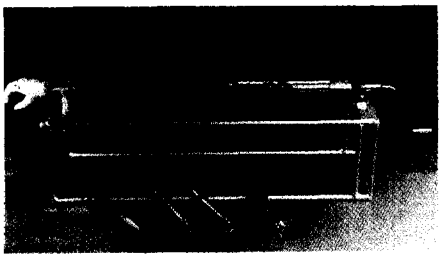
We removed the cosmetic-glove when we did our measurements.

(1) The method of measuring the traction power of the control-cable and distances between fingertips.

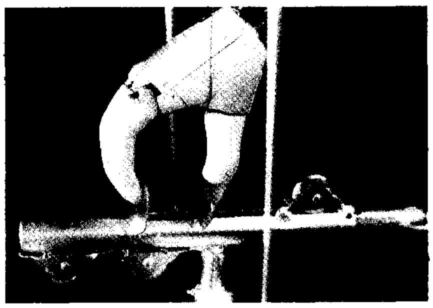
The equipment (Fig.1-a) used for measuring the traction power of the control-cable is comprised of a part that fixes the hand and a handle adding traction power. A spring scale was inserted between a cable attached to the handand the handle to measure traction power. The distance between fingertips was measured with calipers. By gradually increasing the traction power,we observed the response of the spring scale for every 5mm the fingers changed in distance. Then, we started gradually loosening the traction power from where the distance between the fingers was the longest, and we observed the response of the spring scale for every 5mm the distance between the fingers changed.

(2) Measurement of pinch power.

As Figure 1-b indicates,pinch power was measured by having the "hand" pinch two vertical tabs on a pipe attached to the spring scale. We used a pulley to reduce the friction induced between the pipe and vertical tabs.



a:Equipments to measure traction force of control cable.



b:Equipments to measure pinch power of functional prosthetic hand.

Fig.1. Equipments to measure traction force of control cable and pinch power of functional prosthetic hand.

When the subject pinched the two tabs,we measured the traction power. And we noted the response of the spring scale for every 5mm the fingers changed in distance.

2. Electromyography (E.M.G.) of the upper-extremity for grasping actions with the wrist joint and thumb in different positions

Detailed accounts of the muscle that we electromyographed are given below:

1ch : Trapezius (upper fibers).
2ch : Deltoid (anterior fibers).
3ch : Deltoid (middle fibers).
4ch : Biceps brachii.
5ch : Triceps brachii.
6ch : Wrist extensors.
7ch : Wrist flexors.
(ch = channel)

One normal subject was used for the following tests. The subject sat on a 42.0cm-high chair to grasp the 10.0cm-diameter disk set on a 59.5cm-high table. The conditions of these tests are as follows:

1. The subject grasped the disks with the wrist joint fixed at 0 degrees by a "Long Opponens Splint". This trial represents movement using a functional prosthesis (Fig.2-a).
2. The subject again grasped these disks with a "Long Opponens Splint"; however, this time their wrist joints are free (Fig.2-b).
3. The subject grasped these disks with the wrist joint fixed at 0 degrees by a "Long Opponens Splint", but their thumb movements are now free (Fig.2-c).

3. Kinetic analysis of grasping movements

We analyzed each movement as shown in II-1 by using a three-dimensional video.

The three-dimensional video analysis was made by using two 8-millimeter video-cameras and personal-computer. Figure 3 is a block diagram of a three-dimensional video analysis system.

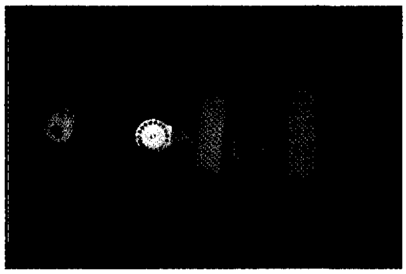
The index markers were attached to the acromion, the lateral epicondyle of the humerus, the styloid process of the radius, the MP joint and nail of the index finger, and the nail of the thumb.

We analyzed the subject's grasping of a disc placed at 30.0cm in front of the subject.

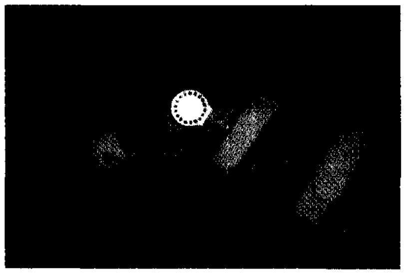
Result

1. Dynamic analysis (Table.1)

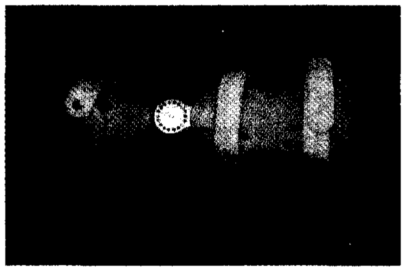
Figure 4-a indicates the characteristics of Hand No.2. All throughout the process, pinch power was maintained at above 2kg and always higher than the



a : Wrist joints fixed.



b : Wrist joints are free.



c : Wrist joints fixed and thumb movements are free.

Fig.2. Using Long Opponens Splint.

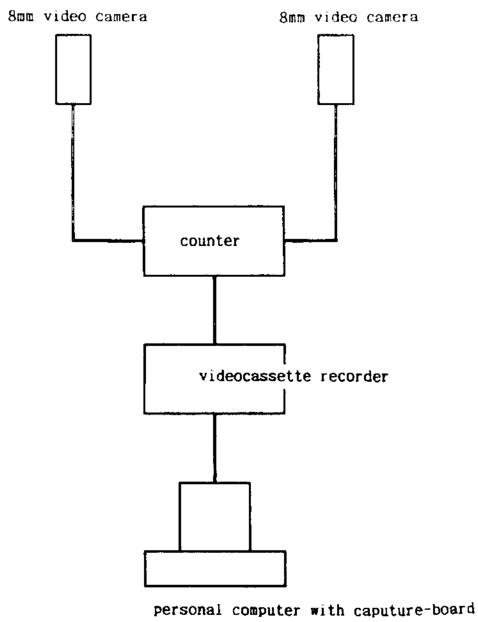


Fig.3. Block diagram of a three-dimensional video analysis system.

traction power.

As the distance between fingertips may be affected by subtle changes in traction power, it is difficult to control the delicate movements.

As pinch power declines when the distance between the fingertips is separated by more than 50mm, it is difficult to grasp larger objects.

The pinch power of hands numbered 3,4,5,8 and 9 is small (Fig.4−b:No.8), and more traction power is necessary for operation. The experiment showed that the small pinch power with the hands closed presents a dynamic problem. To conclude, subtle adjustment of the traction power is necessary to control the distance between fingertips. Moreover, relatively great traction power is required to control the hands. It has also been discovered that pinch power becomes smaller with the hands closed than when they are opened.

2. Kinetic analysis of grasping movements (Figs.5 and 6).

Figure 5 is a front view of a three−dimensional video analysis, represented in a stick picture.

In 1, together with the elevation movement of the elbow joint, internal rotation of the humerus, elevation of the scapula and abduction of the shoulder joint. This action is a compensatory action to put the fore−arm in a pronated position; then the tip of the thumb and the tip of the opposing index and middle fingers became parallel to the surface of the desk. This is identical to the movement of the already existing internally powered prosthesis.

In 2, as well, the compensatory movement of inter−nal rotation of the humerus can be recognized, even though it is more reduced than in 1.

In 3, the appearance of the compensatory move−ment is the least marked of all.

Tab.1. The traction force of control cable and pinch power, the series of mecanical dynamic analysis wer performed 10 utility prosthetic hand

			Traction force			Pinch power		
Fingertips Distance			1 cm	3 cm	5 cm	1 cm	3 cm	5 cm
No	Hand							
1	Dor. S V/O	open close	2.1Kg 1.1Kg	2.2Kg 1.4Kg	3.3Kg 2.2Kg	1.2Kg 0.3Kg	1.0Kg 0.3Kg	1.5Kg 0.5Kg
2	Dor. M V/O	open close	1.1Kg 1.1Kg	2.1Kg 0.7Kg	1.9Kg 0.5Kg	4.2Kg 3.0Kg	4.3Kg 2.8Kg	3.7Kg 2.0Kg
3	Dor. L V/O	open close	5.7Kg 3.4Kg	7.3Kg 4.5Kg	7.0Kg 4.6Kg	9.0Kg 3.0Kg	4.9Kg 2.1Kg	3.8Kg 2.0Kg
4	Rob.soft V/O	open close	6.0Kg 2.8Kg	8.0Kg 3.3Kg	9.5Kg 3.0Kg	7.1Kg 0.6Kg	6.0Kg 1.6Kg	7.5Kg 2.9Kg
5	Rob. M V/O	open close	4.9Kg 3.0Kg	7.8Kg 4.2Kg	9.5Kg 3.2Kg			
6	Otto.S V/O	open close	1.9Kg 0.2Kg	2.8Kg 0.3Kg	4.0Kg 1.2Kg	1.5Kg 0.6Kg	2.0Kg 0.8Kg	2.8Kg 1.0Kg
7	Pass. V/O	open close	2.4Kg 1.7Kg	3.3Kg 2.2Kg	4.4Kg 2.6Kg	1.4Kg 0.6Kg	2.0Kg 0.8Kg	3.3Kg 1.0Kg
8	Beck.M V/O	open close	8.3Kg 1.7Kg	8.8Kg 2.4Kg	8.9Kg 2.3Kg	2.7Kg 0.6Kg	3.5Kg 1.0Kg	3.6Kg 1.2Kg
9	Beck.P V/O	open close	4.4Kg 1.8Kg	6.5Kg 2.5Kg	8.8Kg 3.4Kg	1.4Kg 0.6Kg	2.0Kg 1.4Kg	3.3Kg 1.9Kg
10	Sier. V/C	open close	2.7Kg 2.4Kg	2.8Kg 2.2Kg		Lock Lock	Lock Lock	

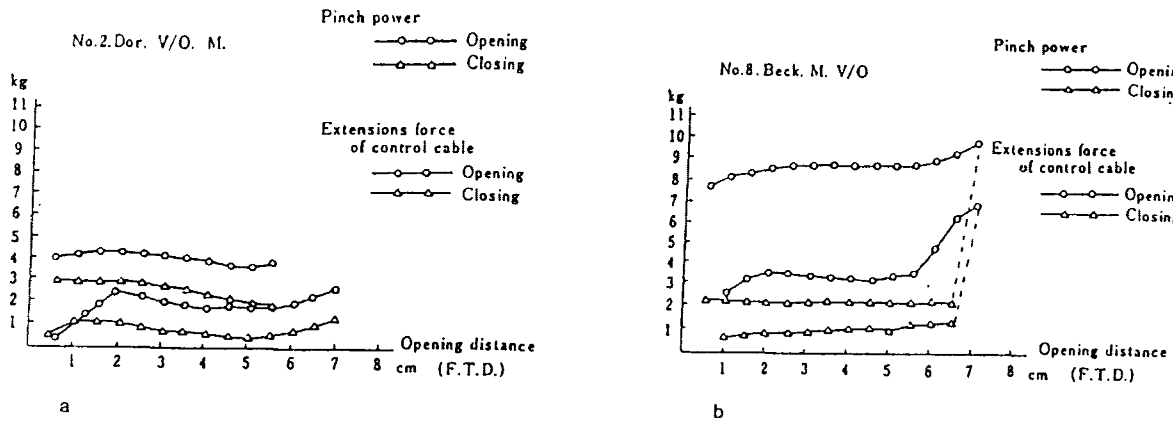
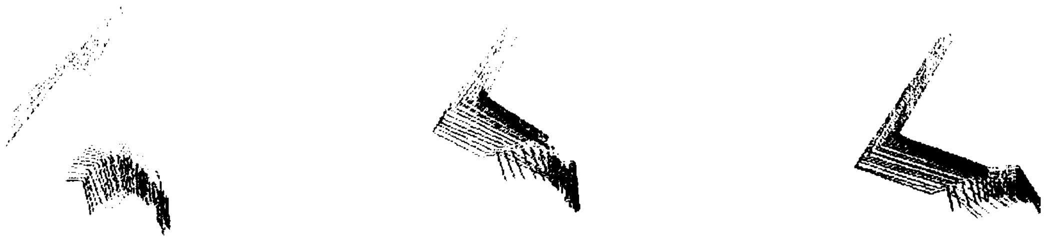


Fig.4 Dynamic analysis of the functional prosthetic hand



A Wrist joints fixed.　B Wrist joints are free.　C Wrist joints fixed and thumb movements are free.

Fig.5 3 Dimansion analysis of upper-extremity movement.

From the preceding observation, we concluded that the compensatory movement of the arm proximal part is prevented either by moving the wrist or by inducing radial abduction of the thumb.

Nevertheless, with internally powered prostheses, it is difficult to exert voluntary control upon the prosthetic wrist joint.

The action pattern which induces radial abduction of the thumb gives rise to a comparatively less compensatory movement. This fact led us to the recognition that it was very important to develop a mechanism in the internally powered prosthetic hand which would induce a radial abduction movement of the thumb.

Next, if we examine the Electromyography (Fig.6), we see that in 3, the muscle action of the shoulder-scapula girdle was smaller than in 1 and 2.

In 1, the muscle action potential of the shoulder girdle can be observed. This is consistent with the results of the three-dimensional analysis.

In 2, as well, the same pattern is indicated.

In 3, we see that although at the beginning of the movement the trapezius muscle displayed activity, during the action of grasping this muscle does not act hardly at all.

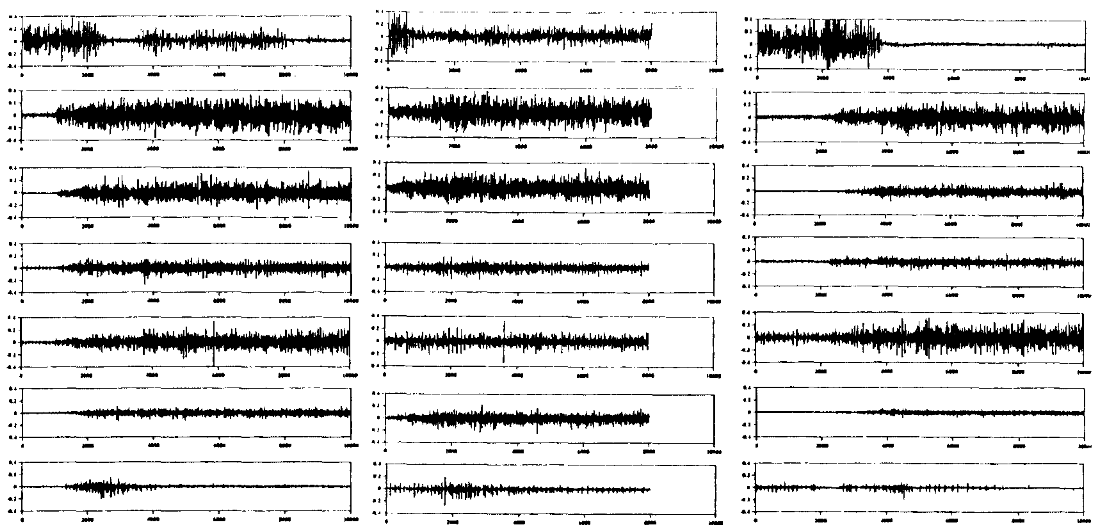
Thus, on the basis of the muscle action potential too, we were able to estimate that to eliminate limitations of thumb movements, a mechanism which allows for a radial abduction movement is superior to other mechanisms.

Discussion

1. Newly-developed Voluntary Opening and Closing Hand(V.O.C.Hand)

The traditional hands are controlled voluntary against the tension of springs and elastic bands. This resistance often causes difficulty in governing the hand.

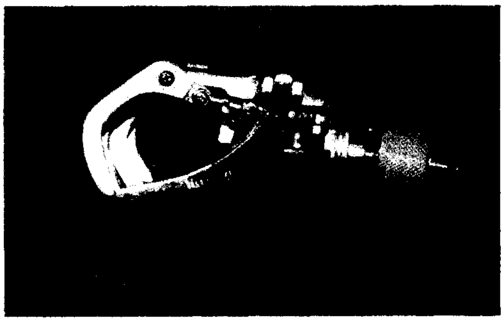
We made the voluntary opening and closing hand through experiment to improve the dynamic advantages of the hand without using the tension of springs and elastic bands.



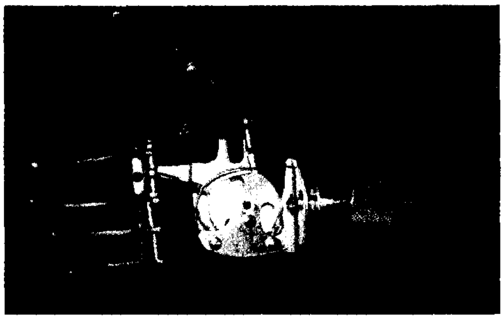
Wrist joints fixed.　Wrist joints are free.　Wrist joints fixed and thumb movements are free

Fig.6 E.M.G.of upper-extremity movement.

This voluntary opening and closing hand uses the opposition movement of the thumb and index and middle fingers (Fig.7). We call it a tree-jaw-check. The movements of the ring and little fingers are linked with that of the index and middle fingers to make palmar side touch of the hand larger and to provide friction when grasping a glass. The opening thumb is positioned in the middle range of radial abduction and palmar abduction to reduce the compensational movement of shoulder and elbow joints. The fingers are controlled by two pairs of cables. These cables turn the 5.0cm-diameter disk and lead the fingers movements.



a : Closing



b : Opening

Fig.7 Voluntary Opening and Closing Hand

2. Evaluation of Voluntary Opening and Closing Hand

The question to be discussed is the relationship of traction power to pinch power in our trial control cable.

Figure 8 shows that traction power is directory proportional to pinch power. From this viewpoint, one may say that the patients using this voluntary opening and closing hand can easily change pinch power consciously. Furthermore,the patients can feel the hardness of the object that he/she will grasp, through the cable.

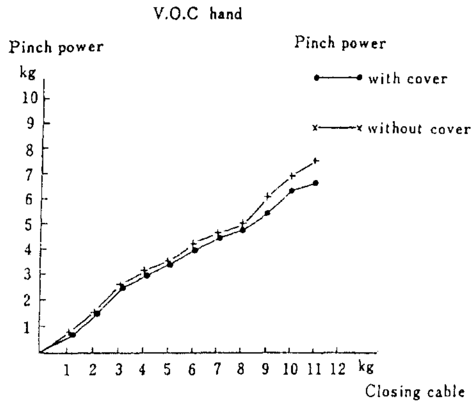


Fig.8 The relation between traction force and pinch power of control cable on Voluntary Opening and Closing Hand

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Research and Development of Internally-Powered Functional Prosthetic Hand based on Ergonomics.

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Abstract

The purpose of this study was develop an internally-powered functional prosthetic hand. To study the function of the prosthetic hand, we conducted the following series of tests: 1) research on the dynamic features of commercialized functional prosthetic hands, 2) analysis of the movement of the thumb in grasping actions. In the first series, we concluded that delicate control of the hand is so difficult that a patient has to have quite strong power. Second analysis showed that the prosthetic hand needs an additional function in mid-range movements, including radial abduction and palmar of abduction. These results have brought about the development of a new type of functional prosthetic hand. This new prosthetic hand was named the "Voluntary Opening and Closing (V.O.C.) Hand".

Key words : internally-powered functional prosthetic hand, voluntary opening hand, voluntary closing hand, dynamic analysis, three-dimensional analysis, electromyography