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Short Report

Changes in Shear Force and Inward Pressure inside Plug-fit Sockets Due to Flexion and Extension of the Elbow Joint

Katsutoshi SENOO[*1], **Daisuke FUJITA**[*1], **Kenichi KOBARA**[*1] and **Manabu YOSHIMURA**[*2]

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Abstract

This study measured shear force and pressure of prosthesis sockets and compared sockets made from conventional hard acrylic resin with soft material. In addition, we also examined how the acrylic resin of the socket influences the decision to put on an elbow system prosthesis. We found that the soft socket extended the range of motion of the elbow joint and permitted movement of the soft tissue to a greater extent than the hard socket. Furthermore, the movable range of the elbow joint widened as the shape of the socket itself changed.

1. Introduction

One of the single most determining factors of whether a person will use a prosthesis is its socket design[1]. The role of the prosthesis socket includes stump storage, transmission of force and motion, support of weight (load), and suspension function[2]. However, weight support in the sockets of upper extremity prostheses is not as important as that of lower extremity prostheses. We developed a forearm body-powered prosthesis (elbow system prosthesis: Figure 1) that uses elbow joint motion as a power source with a plug-fit type socket[3-6]. We confirmed where the soft tissue pressed in the socket as the elbow flexed.

Figure 1 Elbow system prosthesis

[*1] Department of Rehabilitation, Faculty of Health Science and Technology, Kawasaki University of Medical Welfare, Kurashiki, 701-0193, Japan
E-Mail: kse8171@mw.kawasaki-m.ac.jp
[*2] Rehabilitation Center, Kawasaki Medical School Hospital

The sockets of forearm prostheses are self-suspended sockets (Northwestern type socket, Muenster type socket, plug-fit type socket, etc.). Several recent reports have focused on the materials used for sockets and their design but not their hardness[7-10]. It is believed that the soft tissue compression in the socket that accompanies elbow flexion influences the wearing comfort and operability of elbow system prostheses. The contact between the soft tissue and the socket, in the socket, seemed to cause shear force and pressure in this part.

Therefore, the purpose of this study was to measure shear force and pressure inside the socket and to compare a conventional hard acrylic resin socket with a soft material socket. We also investigated whether differences in acrylic resin hardness of sockets could be factors affecting the fit and operability of the elbow system prosthesis.

2. Methods

2.1 Participants

Three healthy male volunteers who had not suffered from any musculoskeletal, neuromuscular, or sensory disorders participated in this study. Shear force, pressure, and range of motion (ROM) of the elbow joint in the socket were measured in two participants, and ROM of the elbow joint alone was measured in three other participants. The study was approved by the Ethics Committee of Kawasaki University of Medical Welfare (16-055). The purpose of this study was explained to all participants and consent was obtained.

2.2 Production of a negative model, positive model, and experimental socket

Production of negative models, positive models, and experimental sockets was conducted by a experienced prosthetist and orthotist.

The negative model was made by casting a bandage from the axilla to the distal part of the forearm at an elbow flexion of 30° and the forearm neutral position. The positive model was made by pouring gypsum into the cast.

The experimental socket was configured to conform to the structure of the elbow system prosthesis (Figure 2). A cuff was fixed to the upper arm with neoprene on the front surface with acrylic resin hardness of 617 H 19 (hard 8: soft 2) 50% and 617 H 17 (hard 0: soft 10) 50%. The elbow joint was made with one multi-axis elbow hinge joint (KI-H-025-1) on the outside. The hardness of the acrylic resin of the socket was set as hard socket (617 H 19; hard 8: soft 2) and soft socket (617 H 19; hard 0: soft 10). To insert a healthy upper limb into the socket, the outer side of the front of the socket was split and fixed with velcro tape after inserting the upper limb.

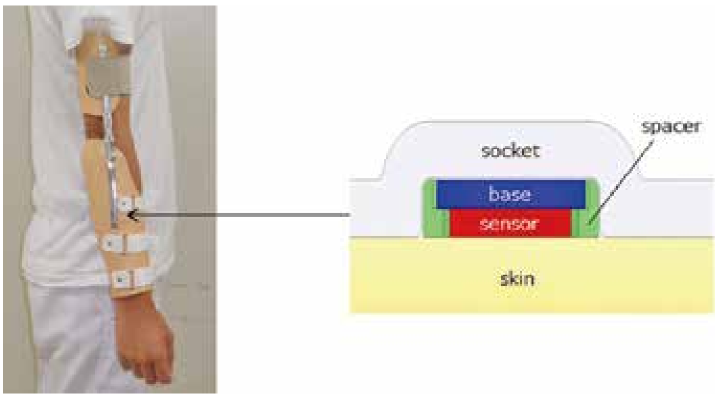

Figure 2 Experimental socket

The sensor was recessed in the socket and brought into contact with the skin as being flush with the socket.

2.3 Measurements of the experimental sockets

Shear force and pressure were measured using a shokkakuchippu^{TM} (Touchensu Corporation). The sensor is shown in Figure 3. The sensor has fine piezo resistance arranged in three axial directions; therefore, it was possible to simultaneously record the shear force in the parallel (x-axis) and long-axis (y-axis) directions and the force in the vertical direction (z-axis). The sampling frequency was 20 Hz, and the unit of force was recorded in Newton (N). The measured value of the vertical force (z-axis) was divided by the area of the sensor and the units were converted to pressure (kPa). The sensor was attached to the medial, lateral and posterior sides on the basis of 2 cm below the center of the trimming line on the anterior of the socket. The installation of the sensor is shown in Figure 2.

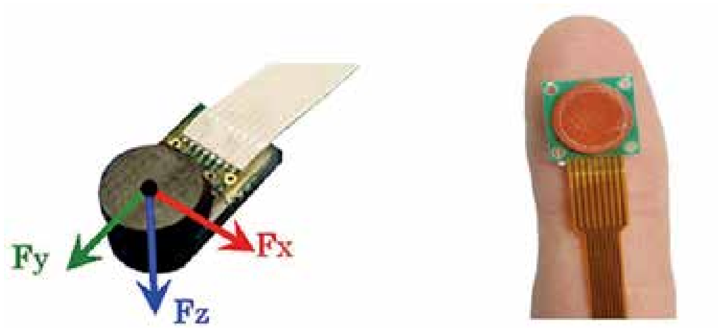

Figure 3 Small and thin shear force and pressure sensor that can be inserted in the socket (shokkakuchippu^{TM}: Touchensu Corporation).

Diameter: 8 mm Base: 1 cm^2 Thickness: 2 mm

(source: http://touchence.jp/)

2.4 Experiment procedures

The ROM of the elbow joint was measured using a goniometer while the participants put on the socket and made several elbow joint movements. The sensor was installed after ROM measurement. Participants practiced flexion and extension movement of the elbow joint in time with a metronome (30 bpm), and the experimenter to determine whether the sensor was activated normally. The motion speed of the elbow joint was 2 s from the maximum extension position of the elbow joint to the maximum bending and 2 s from the maximum bending to the maximum extension. After practicing with the socket, elbow joint motion using the hard socket was measured 30 times, where one count was taken as maximum bending back to maximum extension and back to maximum bending. After resting for 10 min, data were also collected for the soft socket in a similar manner.

2.5 Data analysis

Data were analyzed to compare (1) elbow joint ROM in hard with soft sockets and (2) shear force and pressure in hard with soft sockets. The difference between the maximum and the minimum values of the x-axis (parallel), y-axis (long axis), and z-axis (pressure) from the 11th to the 20th elbow joint movements of the two participants were calculated (Figure 4). Statistical analysis using Wilcoxon's signed rank sum test was used to compare elbow joint ROM in hard with soft sockets, with the significance level set to less than 5%. Data were analyzed by using SPSS 24.0 software.

3. Results

The ROM of the elbow joint was 124.0 ± 9.7° for the hard socket and 134.0 ± 8.6° for the soft socket ($p = 0.003$). Extension was -6.0 ± 8.0° for the hard socket and -4.0 ± 5.8° for the soft socket ($p = 0.177$).

The shear force and pressure of the hard and soft sockets are shown in Table 1. The difference between

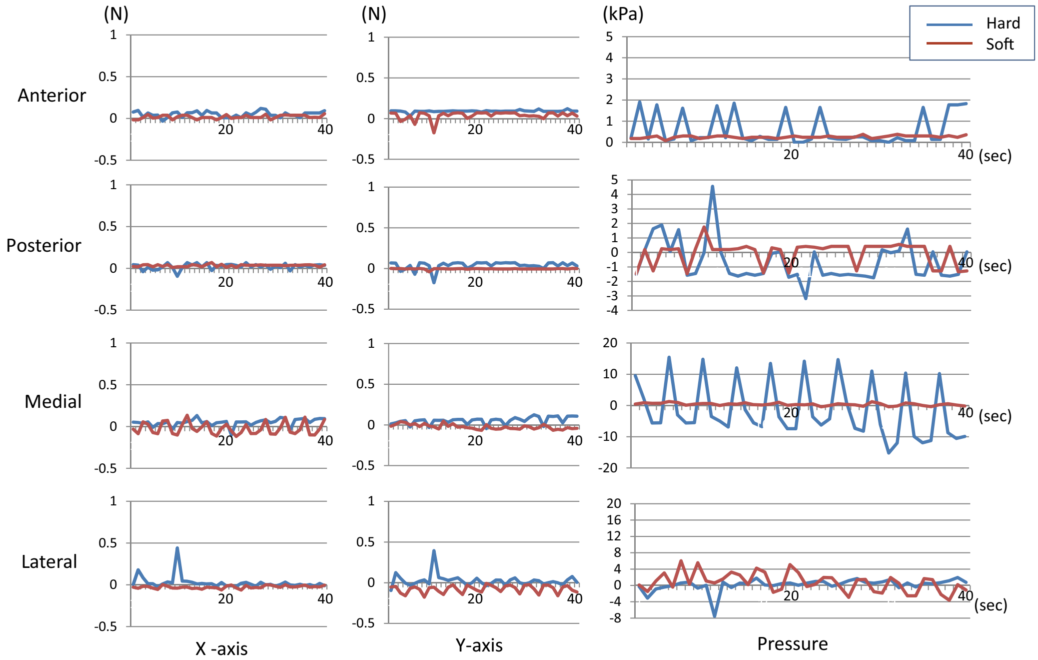

Figure 4 Values recorded during elbow flexion/extension movement

Examples of maximum and minimum values for medial pressure obtained for participant B are shown. Units are X and Y (N), pressure (kPa).

Table 1 Shear force and pressure of hard and soft sockets of two participants (A and B)

	Anterior											
	X-axis (N)				Y-axis (N)				Pressure (kPa)			
	hard		soft		hard		soft		hard		soft	
Participant	A	B	A	B	A	B	A	B	A	B	A	B
maximum	0.02	0.12	0.71	0.06	0.06	0.05	0.01	0.12	0.10	1.91	1.59	0.38
minimun	-0.34	-0.03	-0.03	-0.02	-0.04	-0.02	-0.10	0.03	-0.72	0.00	-0.10	0.08
difference	0.36	0.15	0.74	0.07	0.10	0.08	0.11	0.09	0.82	1.91	1.69	0.30
	Posterior											
	X-axis (N)				Y-axis (N)				Pressure (kPa)			
	hard		soft		hard		soft		hard		soft	
Participant	A	B	A	B	A	B	A	B	A	B	A	B
maximum	0.07	0.07	0.09	0.07	0.00	0.07	0.00	0.00	1.65	4.56	0.54	1.75
minimum	0.01	-0.10	0.02	0.01	-0.01	-0.18	-0.01	-0.04	-1.85	-3.18	-1.61	-1.47
difference	0.06	0.16	0.07	0.06	0.01	0.25	0.01	0.04	3.50	7.74	2.15	3.22
	Medial											
	X-axis (N)				Y-axis (N)				Pressure (kPa)			
	hard		soft		hard		soft		hard		soft	
Participant	A	B	A	B	A	B	A	B	A	B	A	B
maximum	0.38	0.13	0.03	0.14	0.15	0.12	0.07	0.05	1.38	15.44	1.78	1.27
minimum	-0.02	-0.10	-0.26	-0.12	0.00	-0.05	0.01	-0.07	-0.46	-15.18	0.36	-0.41
difference	0.41	0.23	0.29	0.25	0.15	0.17	0.07	0.11	1.83	30.62	1.43	1.68
	Lateral											
	X-axis (N)				Y-axis (N)				Pressure (kPa)			
	hard		soft		hard		soft		hard		soft	
Participant	A	B	A	B	A	B	A	B	A	B	A	B
maximum	0.10	0.44	0.14	0.00	0.19	0.39	0.23	-0.01	35.26	1.94	33.94	6.01
minimum	-0.02	-0.02	0.04	-0.06	-0.07	-0.10	-0.16	-0.18	-5.81	-7.54	-9.12	-3.62
difference	0.12	0.47	0.10	0.06	0.26	0.49	0.39	0.17	41.07	9.48	43.06	9.63

the shear force of the hard and soft sockets (x- and y-axes) was within 1 N in the anterior, posterior, medial, and lateral sides. The differences in pressure (z-axis) between the hard and soft sockets were greatest on the anterior side for one participant wearing a soft socket and for one participant wearing a hard socket; the pressure in the hard socket was high for both the posterior and medial sides. Furthermore, the pressure in the soft socket was high for both participants on the lateral side.

4. Discussion

An elbow system prosthesis is defined as a body-powered prosthesis that uses elbow joint motion as a power source. The role of that socket is stump storage and transmission of force and motion. To fulfill these roles, the acrylic resin used to make the socket requires some hardness because soft socket expansion may extend the ROM of the elbow joint.

A limiting factor of elbow joint flexion movement is the quantitative increase in the flexion side soft tissue due to flexor group contraction[11]. In other words, the flexion movement of the elbow joint is limited by contact between the upper arm and the forearm where a quantitative increase occurs. Even if the upper arm and the forearm are in contact with each other (for example, in a healthy upper limb), the soft tissue of the elbow flexure ROM is moved and secured to approximately 145°. The socket of the elbow system prosthesis was made using a negative model created without muscle contraction. In addition, the soft socket allowed movement of the soft tissue to a greater extent than did the hard socket, suggesting that the movable range of the elbow joint increases as the shape of the socket itself changes. Therefore, we concluded that the ROM limitation became larger than the healthy upper limb as the soft tissue interfered with the movement coming into contact with the upper arm earlier. In addition, soft sockets allow soft tissue to migrate rather than hard sockets, leading to reduced ROM limitation. Although these shear forces are small in the socket, the pressure in the socket tends to increase and decrease with flexion and extension of the elbow joint.

In conclusion, the hardness of the acrylic resin of the socket and the conformity of the shape of the soft tissue can expand the ROM of the elbow joint. This can improve the feeling and fit of an elbow system artificial hand and its operation.

Acknowledgements

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