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Technical Note

Novel knit fabric rehabilitation equipment for finger impairment

Tomoo Mano, MD, PhD[1, 2)*], Shigekazu Fujimura, RPT[3)], Shigenobu Amari[4)], Yoshikazu Yamamoto[4)], Satoshi Nakayama[5)], Akira Kido, MD, PhD[2)]

1) Department of Neurology, Nara Medical University: 840 Shijo-cho, Kashihara 634-8521, Japan
2) Department of Rehabilitation Medicine, Nara Medical University, Japan
3) Medical Technology Center Division, Nara Medical University Hospital, Japan
4) MIKASA Company Limited, Japan
5) MBT (Medicine-Based Town) Institute, Nara Medical University, Japan

Abstract. [Purpose] Intensive training can at least partially improve finger movement dysfunction observed after stroke or any neurodegenerative disease. Wearable equipment can significantly improve patients' quality of life. However, long-term use of conventional training gloves containing metal can injure joints. In this study, we investigated the safety and efficacy of a novel, metal-free, wearable strength-building device. [Participants and Methods] We enrolled 20 healthy participants in whom we measured grip and pinch strength before and while the equipment was worn. Additionally, we investigated the adverse effects and discomfort experienced while participants wore the equipment. [Results] The grip strength was reduced by approximately 20% while participants wore the equipment. We did not observe any serious adverse events. [Conclusion] The knitting equipment described in this study resists movements associated with gripping the hand and acts on all fingers, and may be useful for rehabilitation to improve finger function during routine activities.

Key words: Rehabilitation, Knit fabric, Finger function

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INTRODUCTION

Functional impairment of fingers and hands, due to causes such as stroke or neurodegenerative disease, can be partially improved by intensive training. The hand is a fundamental element of evolution in human beings and plays an important role in interactions with the environment[1)]. Changes in the functional capabilities of the hand can directly impact the activities of daily living (ADL)[2)]. Therefore, correct assessment of its functions is important for planning any rehabilitation processes[3)]. Traditional physical therapy can improve finger function, but it is expensive, labor-intensive, and likely dosage dependent. Additionally, it does not provide quantitative data about the patient's performance and improvement[4)]. Hand rehabilitation programs do not help in regaining functions up to the levels of ADL, because these cannot be used daily. Training with wearable rehabilitation equipment can help maintain and improve the ADL. However, most equipment is made of metal and cause discomfort, and therefore have not been adapted to ADL[5)].

Conventional support gloves are constructed by sewing a bone member to the back of the hand. However, since the bone member has similar characteristics at the joint and the inter-articular part, wearing it over long periods of time leads to joint damage. If a material that does not damage the joint is selected, its elasticity is usually low, and the desired support effect is not obtained. Therefore, we created a novel, metal-free, wearable strength-building equipment by stitching stretchable threads in a unique way and evaluated the safety and efficacy of this knit fabric equipment.

*Corresponding author. Tomoo Mano (E-mail: manoneuro@naramed-u.ac.jp)

PARTICIPANTS AND METHODS

We have composed this equipment from various characteristic knitting methods. It has two parts: a palm and a back. The palm has inlay knitting, while the back has inlay knitting and flechage knitting. The front has Nylon (NY) thread (NY) while the back has Polyurethane (PU) and Polyethylene, which also makes up the remaining parts of the glove. Rubber threads are inserted into all parts of the glove by inlay knitting (also called insertion knitting).

We have also changed the balance of the knitting. The area of the back has been kept smaller than the palm by using inlay-knitted fabric with flechage knitting and partial tuck knitting. At the fingers as well, the area of the back is smaller than that of the front part by using inlay knitting at the back with the inlay into a tuck knit (Fig. 1A). The fingers and palm are composed similarly; consequently, the fabric warps toward the back of the finger. By adding flechage knitting to both the sides of the fingers on the instep side of each knuckle, each joint is further sharpened and bends back to the in-step side. The ease of knitting and the elasticity of the fabric are obtained by using yarns with stronger elasticity for the back that are attached to the front yarns. The tip of the distal interphalangeal joint is kept open so that the equipment can be easily attached and detached (Fig. 1B, C).

We used a device for individually measuring the reaction force (torque) applied to each joint of all the fingers of the orthodontic glove (up to 14) (Nikoseiki, Gifu, Japan) (Fig. 2A–C). It is composed of a model part for the hand while wearing the gloves, and a base part with a measuring device. The desired position of the hand when wearing gloves, and when measuring each joint of each finger, is easily achieved. After the position is achieved, it is fixed by a strong magnet from the back of the base. With the participants wearing the gloves, the reaction force was measured (Newton) when returning to the position where it becomes level with the palm using a push bull gauge. Measurement protocols: (1) Measurements were taken at the numerical point of the scale (retrofitted) set for each part of each finger. (2) The equipment was attached to the base of the finger when measuring metacarpophalangeal joint (MP) of each finger. (3) The proximal interphalangeal joint (PIP) for each finger was measured by attaching the tip of the fabric to the tip of the intermediate phalanx (without covering the first joint through the hole with the fabric). (4) Measurements were taken by wearing the equipment with the through-hole of the first joint visible (do not cover the through-hole with fabric).

We enrolled 20 participants, after evaluating their eligibility, between December 2020, and March 2022 at Nara Medical University Hospital. The selection criteria for the participants were as follows: inclusion criteria of normal healthy adults and exclusion criteria of those with the medical history of stroke and neuromuscular disease, those with skin lesion in palm and back, those who take medications, those who consumed alcohol before the study, and those who were overweight. Grip strength and pinch strength were measured before and during equipment-wearing with a 10-minute resting. Grip strength, which is a measure of the muscular strength, or the maximum force generated by the forearm muscles, can be used as a screening tool for the measurement of upper body strength and overall strength. Pinch strength is the ability to hold something between the thumb and finger[3]. The thumb applies an inward force, which is balanced by one or more fingers applying a force back toward the thumb. We recorded three pinch strengths; tip, palmar, and lateral pinch), three times at 1-minute intervals, and recorded the maximum strength recorded for each time. This study was approved by the Ethics Committee of Nara Medical University (2231). All study procedures were performed in accordance with the ethical standards of the ethics

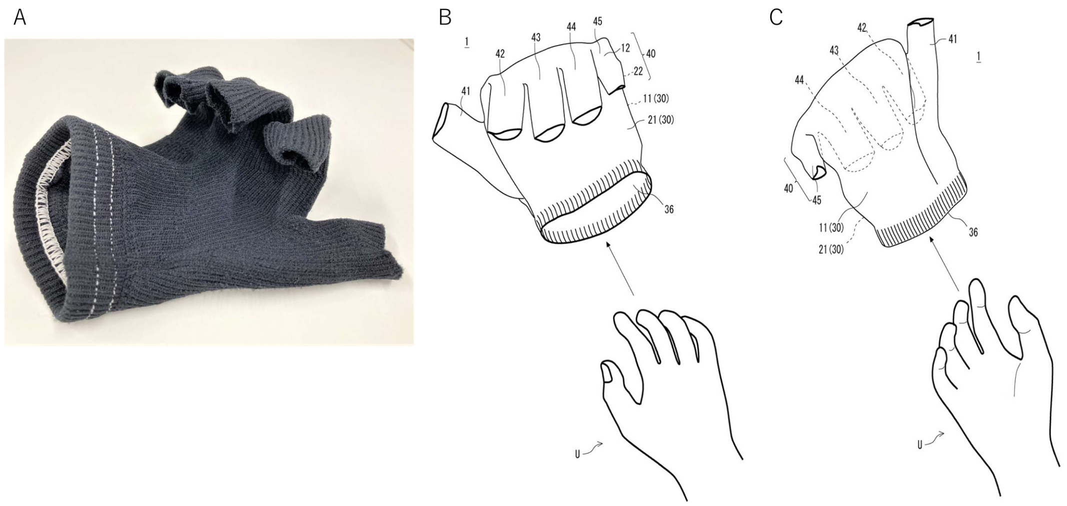

Fig. 1. Novel rehabilitation equipment of knit fabric for finger impairment.
A; A novel, metal-free, wearable strength-building equipment by stitching stretchable threads in a unique way. B, C; The way to wear the gloves.

committee, Declaration of Helsinki, and Ethical Guidelines for Medical and Health Research Involving Human Subjects in Japan. All participants provided written and verbal informed consent after receiving information about the study.

Statistical analyses were performed using SPSS version 22.0 (SPSS Japan, Tokyo, Japan). The Shapiro–Wilk test was used to assess data distribution. The paired two-tailed t-test was used to compare the results before and during treatment. We adopted a significance level denoted by alpha (α) as a pre-chosen probability for significance; 0.05 (statistically significant) and 0.001 (statistically highly significant). p=0.05 means that there is a 5% probability that the results are due to random chance and p=0.001 means that the chances are only one in a thousand.

RESULTS

The reaction force (torque) applied to each joint of each finger of the glove is presented in Table 1. Proximal joints exerted a greater force than distal joints on all fingers, with highly reliable values.

The clinical characteristics of the participants are presented in Table 2. The comparison between before and during- wearing gloves revealed that the grip strength and the lateral pinch strength were highly significant decreased ($p<0.001$). The tip and palmar pinch strengths were decreased significantly (p=0.013, p=0.015). No serious adverse effects and psychological effects were reported while wearing the equipment; however, the participants did experience minor discomfort, such as tightness (16/20), fatigue (10/20), and excessive heat (8/20), which did not affect the ADL. All participates could wear and remove the glove easily. The attachment/detachment time was under 30 seconds, and there were no skin problems associated with attachment or detachment.

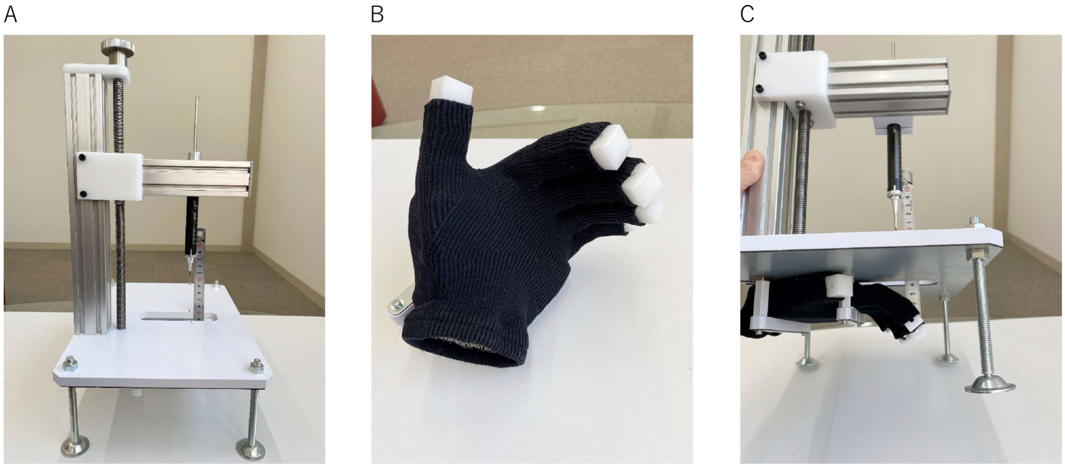

Fig. 2. Novel rehabilitation equipment of knit fabric for finger impairment.
A–C; A device for individually measuring the reaction force (torque) applied to each joint of all the fingers of the glove.

Table 1. Strength of novel glove

Measurement site	1st	2nd	3rd	Average
Thumb IP	0.60	0.60	0.60	0.60
Thumb MP	0.70	0.75	0.70	0.72
Index finger PIP	0.70	0.65	0.70	0.68
Index finger MP	1.25	1.20	1.20	1.22
Middle finger PIP	0.85	0.90	0.85	0.87
Middle finger MP	1.30	1.30	1.25	1.28
Ring finger PIP	0.75	0.75	0.75	0.75
Ring finger MP	1.20	1.20	1.20	1.20
Little finger PIP	0.55	0.55	0.55	0.55
Little finger MP	0.90	0.95	0.95	0.93

The unit of data are newton. MP joints exerted a greater force than PIP and MP joints.
IP: interphalangeal joint; MP: metacarpophalangeal joint; PIP: proximal interphalangeal joint.

Table 2. Participant characteristics

Characteristics	Participants (n=20)	
Age (years)	35.7 ± 9.5	
Gender	Male: 9, Female:11	
BMI (kg/m^2)	25.1 ± 3.6	
The muscle strength before and during wearing	Before	During wearing
Grip strength (kg)**	33.9 ± 10.0	26.8 ± 8.1
Tip pinch (kg)*	5.8 ± 3.1	5.3 ± 3.3
Palmar pinch (kg)*	7.7 ± 3.7	7.1 ± 4.0
Lateral pinch (kg)**	9.6 ± 4.1	7.5 ± 3.6

Data are shown as mean ± SD (range) and number (percentage). The comparison between Before and During wearing was used the t-test. Grip strength and Lateral pinch were strongly significant change between before and during wearing, tip pinch and palmar were significant change. *p<0.05, **p<0.001. BMI: body mass index.

DISCUSSION

Rehabilitation medical equipment can be broadly divided into two types: assisting and training equipment. Assisting equipment improve the quality of life; however, their movements slacked neurologic impairment[6]. Training equipment are handgrip, rubber ball, and wearable equipment. Most wearable equipment is conventionally made of metal and hence is uncomfortable to wear. In recent years, softer materials are being preferred for rehabilitation. We created a training equipment using knitting techniques with a stretchable surrounding fabric. Knitting is much faster than weaving, and is a versatile manufacturing process, as entire garments can be manufactured on a single machine. Knit fabrics are made by interloping one or more sets of yarns[4]. Common examples of apparel utilizing knit fabrics are socks, gloves and sweaters. We believe that by wearing this equipment on a daily basis, it will be possible to achieve finger function that is closer to normal. The results of our study suggest that this equipment adds resistance to the fingers, which may help to improve motor function of the fingers. The tip of the distal interphalangeal joint is open; thus, it can be easily attached and detached, and the traction is higher in the proximal joint than in the distal joint.

In this study, the grip strength and lateral pinch force were significantly reduced during wearing. These results may reflect the characteristics of this equipment, which has a higher traction in the more proximal joint. This equipment facilitates the performance of ADL while applying 20% traction. This can be expected to result in an improvement of finger strength, as well as agile movements and dexterous movements, thus mitigating the ability disorder.

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Conflict of interest

The authors declare no conflict of interest.

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