ORIGINAL ARTICLE

Printing a static progressive orthosis for hand rehabilitation

Li-Ying Huang[a,b], Tien-Hsiang Wang[c,d,e], Bao-Chi Chang[b,f], Chia-I Huang[b], Li-Wei Chou[a,*], Shyh-Jen Wang[b,g,h,*], Wei-Ming Chen[d,i,*]

[a]Department of Physical Therapy and Assistive Technology, National Yang Ming Chiao Tung University, Taipei, Taiwan, ROC; [b]Rehabilitation and Technical Aids Center, Taipei Veterans General Hospital, Taipei, Taiwan, ROC; [c]Division of Plastic Surgery, Department of Surgery, Taipei Veterans General Hospital, Taipei, Taiwan, ROC; [d]School of Medicine, National Yang Ming Chiao Tung University, Taipei Taiwan, ROC; [e]Department of Mechanical Engineering, National Central University, Taoyuan, Taiwan, ROC; [f]Department of Biomedical Engineering, Chung-Yuag Christian University, Taoyuan, Taiwan, ROC; [g]Division of Experimental Surgery, Department of Surgery, Taipei Veterans General Hospital, Taipei, Taiwan, ROC; [h]Institute of Hospital and Health Care Administration, National Yang Ming Chiao Tung University, Taipei, Taiwan, ROC; [i]Department of Orthopedics and Traumatology, Taipei Veterans General Hospital, Taipei, Taiwan, ROC

Abstract

Background: Static progressive orthosis is used for the treatment of severe joint contracture after trauma and/or surgery. However, a custom-fabricated static progressive splint would be expensive and labor intensive. Especially, owing to very limited payment under the current Taiwanese National Health Insurance, the incentives to fabricate a patient-specific splint are insufficient for a therapist. To ease splint construction, we introduced three-dimensional (3D)-printed "shark fin"-shaped device works as a static progressive orthosis for the hand rehabilitation. The aim of this study was to describe and demonstrate the newly designed device.

Methods: This study included a 46-year male suffered from a left distal radius fracture and underwent open reduction internal fixation and a 23-year male with the right thumb flexor pollicis longus rupture, requiring tendon repair. Both subjects used this "shark fin"-shaped device to stretch for increasing range of motion (ROM) of wrist extension and the thumb.

Results: The patient receiving ulnar shortening surgery used this device to stretch for increasing ROM of wrist extension. The active ROM of wrist extension improved from 30° to 50°. The other patient with the right thumb flexor pollicis longus rupture suffered from thumb contracture; the ROMs of the metacarpophalangeal (MCP) joint and interphalangeal (IP) joint were 40°–55° and 20°–25°, respectively. After tenolysis surgery, his ROMs of the MCP and IP joints were improved to 10°–35° and 40°–65°, respectively. Following physical therapy by applying the device, his ROMs of the MCP and IP joints were further increased to 0°–40° and 25°–70°, respectively.

Conclusion: Incorporating the "shark fin"-shaped orthosis into hand rehabilitation increased the ROM of wrist extension for a patient with distal radius fracture and improved the ROM of the MCP and IP joints in another patient after tenolysis surgery.

Keywords: 3D printing; Hand rehabilitation; Interphalangeal joint; Joint contracture; Metacarpophalangeal joint; Radius fracture; Static progressive orthosis; Tenolysis

1. INTRODUCTION

Static progressive orthosis is defined as the use of inelastic components for applying torque to a joint to statically position it as close to the end range as possible, thus increasing passive the range of motion (ROM).[1] Static progressive orthosis is used for the treatment of severe joint contracture after trauma and/or surgery. The underlying mechanism of static progressive orthoses on contracture wounds is based on creep and stress relaxation.[2] Studies have further demonstrated the effectiveness of bracing in the treatment of restriction of elbow mobility,[3] consistent improvements in restoring ROM in patients with posttraumatic elbow contractures,[4] and positive outcomes for patients with upper extremity joint stiffness or contractures due to orthopedic conditions.[5]

However, a physical or occupational therapist must have the skills and time to fabricate a patient-specific splint. Indeed, a custom-fabricated static progressive splint, using assembly hook, loop tapes, static line, hinges, turnbuckles, screws, and gears, would be expensive and labor intensive.[1] Especially, in Taiwan, incentives to fabricate a patient-specific splint are insufficient for a therapist, owing to the limited payment under the current Taiwanese National Health Insurance.

To ease splint construction, we designed an assistant device to function as a static progressive orthosis. In the design, factors including cost, weight, bulk, stability on the arm, material, and

*Address Correspondence. Dr. Li-Wei Chou, Department of Physical Therapy and Assistive Technology, 155, Section 2, Linong Street, Taipei 112, Taiwan, ROC. E-mail address: lwchou@ym.edu.tw (l.-W. Chou); Dr. Shyh-Jen Wang, Rehabilitation and Technical Aids Center, 201, Section 2, Shi-Pai Road, Taipei 112, Taiwan, ROC. E-mail address: wangsj@vghtpe.gov.tw (S.-J. Wang); Dr. Wei-Ming Chen, Department of Orthopedics & Traumatology, 201, Section 2, Shi-Pai Road, Taipei, 112 Taiwan, ROC. E-mail address: wmchen@vghtpe.gov.tw (W.-M. Chen).

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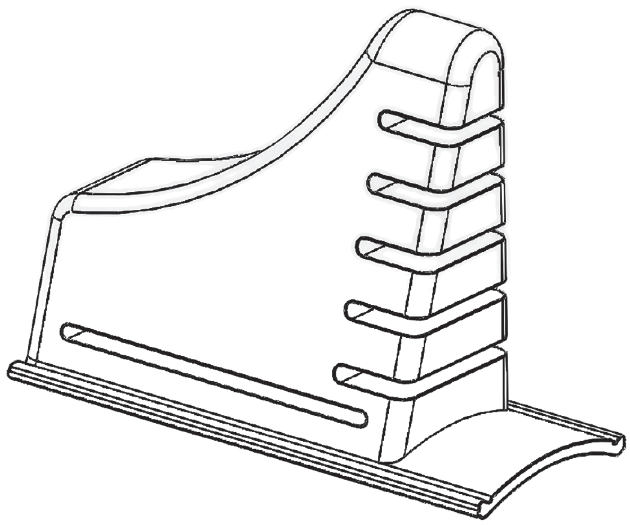

Fig. 1 The CAD model of shark fin-shaped device for the hand rehabilitation.

gadget tolerance and compliance were considered.[1] The three-dimensional (3D)-printed "shark fin"-shaped device works as a static progressive orthosis for the hand rehabilitation. The aim of this study was to describe and demonstrate the newly designed device.

The hand rehabilitation orthosis is essentially wedged similar to a shark fin. As shown in Fig. 1, the bottom of the device is equipped with a cured surface to be fitted on the forearm and penetrating slot to be fixed with straps. Moreover, we designed the device with several undercuts on a side to hold the static line. The other end of the static line was a finger ring to provide positioning, stretching, or muscle-strengthening.

The contracture of metacarpophalangeal (MCP) joints, such as soft-tissue injury caused by burns, would limit the activity of joints.[6] We applied the shark fin-shaped device to provide a steady force on the joints. As shown in Fig. 2, we first attached a splint on the palm and forearm to avoid the flexion of the wrist joint. Following which, the shark fin-shaped device was tightened on the splint. One end of the static line was set on the undercut of the device, and the other end of the line was equipped with a finger ring to be placed on the proximal phalange. The static line was kept perpendicular to the phalange to provide adequate torque. Thus, these undercuts on hand rehabilitation devices would make the static line have an adequate angle related to the phalange. Similarly, we also applied the hand rehabilitation device to patients suffering from contracture of

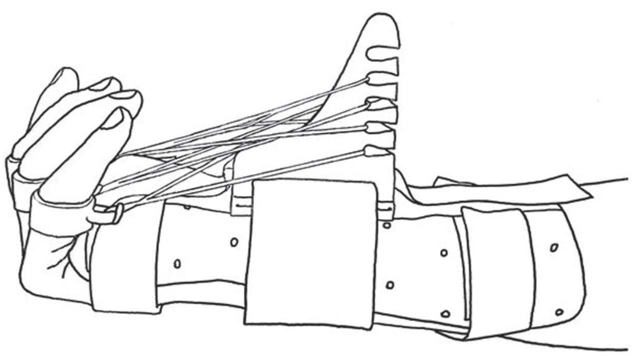

Fig. 2 Using the device to stretch metacarpal phalangeal joint.

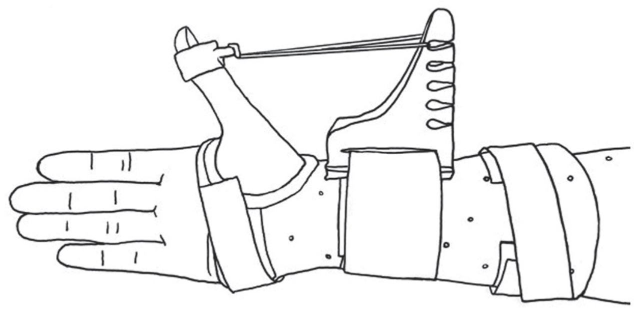

Fig. 3 Using the device to provide a steady force on the thumb.

interphalangeal (IP) joints, such as caused by burns and injury of the IP joint of the thumb or tendon adhesion.

Another application of the rehabilitation device is scar contracture near the thumb. Scar contracture may cause the thumb to be unable to extend on the radial side or opposition. Thus, a patient with scar contracture near the thumb may have difficulty using keyboard or grabbing things. The device may be used for providing a steady force on the thumb, thus progressively increasing its activities. As shown in Fig. 3, we first attached a splint on the palm and forearm to avoid the flexion of the wrist joint. Then, the rehabilitation device was tightened on the splint. One end of the static line was set on the undercut of the device, and the other end of the line was equipped with a finger ring to pull the thumb. The static line was kept perpendicular to the thumb for providing adequate torque.

Furthermore, we can also use the device to pull the radiocarpal joint. As shown in Fig. 4, we attached the rehabilitation device to a splint on the dorsal side of the forearm and then dragged the palm by fixing the strip on the device. To apply a steady progressive pulling force, the strip was fixed on the upper position of the wedge of the rehabilitation device because the stretch angle of the radiocarpal joint would be limited since the beginning. After improvement, the strip should be moved down on the wedge to provide adequate torque. This application can increase the ROM of wrist extension. Likewise, if this device is placed on the volar side of the forearm, it can be applied to increase the ROM of wrist flexion.

2. METHODS

2.1. Subjects

This study included two patients. A 46-year male suffered from a left distal radius fracture and underwent open reduction internal fixation. After receiving ulnar shortening surgery, he still

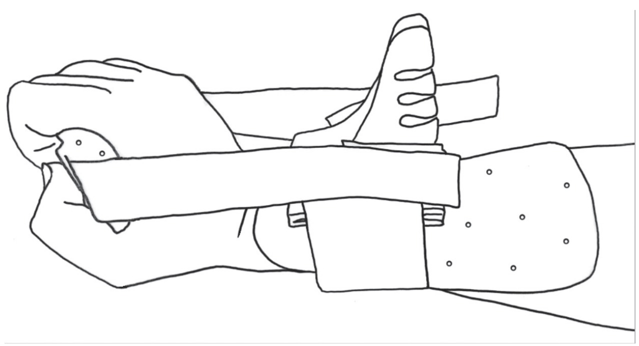

Fig. 4 Using the device to pull the radiocarpal joint.

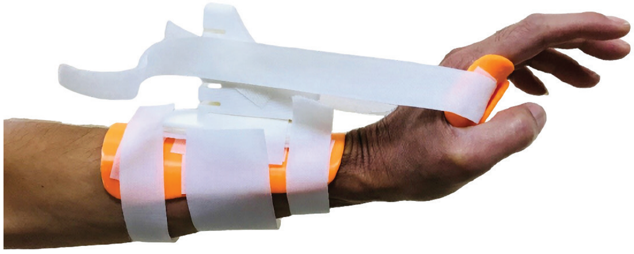

Fig. 5 Using the device to pull the radiocarpal joint for a patient with distal radius fracture.

Fig. 6 Using the device to maintain and increase range of motion (ROM) of the thumb for a patient with flexor pollicis longus (FPL) tenolysis.

complained of a limited ROM of wrist and fingers. He used this device to stretch for increasing ROM of wrist extension (Fig. 5). The other case was a 23-year male with the right thumb flexor pollicis longus (FPL) rupture, requiring tendon repair. After tenolysis surgery, a static extension splinting between exercises and at night was recommended.[7] He further used this device to increase the ROM of the thumb (Fig. 6).

The subject's maximum active ROM was recorded using standard goniometry methods[8] and was measured by the same author (L.-Y.H.). The subject maximally flexed the joint observed. The measurer held a goniometry along the lateral aspect of the joint and then recorded the flexion noted. Other than ROM, patient-reported outcome measures (PROMs) are also important tools for assessing outcomes following injuries to the hand and wrist.[9] PROMs is a valuable tool for gathering quantitative information about the experience of a patient, evaluating the progress of patient cohorts over time, facilitating comparison between groups in clinical trials and auditing surgeons' own performance. The disabilities of the arm, shoulder, and hand questionnaire is well established and was by far the most commonly used PROM.[10] However, restoration of wrist and forearm ROM, strength, and function are among the primary goals of rehabilitation after distal radius fracture.[11] Thus, we only assessed ROM for these two subjects included in this study. The study was approved by the Institutional Review Board of the Taipei Veterans General Hospital (VGHIRB No: 2020-04-010AC).

2.2. 3D modeling and printing

We utilized the DesignSpark Mechanical (RS Components, Corby, UK, and Ansys, Inc., PA), a free 3D computer-aided design (CAD) software, for building this rehabilitation device model. The main concept is a multifunctional design that meets various clinical applications. Furthermore, we also aimed to quickly assemble with ease of use. As described earlier, the bottom of this "shark fin"-shaped device is a curved surface that matches the contours of forearm, and a penetrating slot near the bottom secures the device on the forearm with straps. Several undercuts on the lateral side can be used to hold the static line. This model, created with 3D CAD software, was then saved in the stereolithography (.stl) format for 3D printing.

We believed that 3D printing technology, known as additive manufacturing creating the object by building upon successive layers of material, would adequately fabricate this "shark fin"-shaped device.[12] Before putting the design into manufacture, finite element (FEM) analysis was completed to ensure that the structure could sustain mechanical forces from repeated use. The FEM simulation demonstrated the stresses onto the device were well below both tensile strength and fatigue limit. Furthermore, this orthosis is fixed on a splint using touch fasteners. The actual stresses applied on the device should be much lower than that of simulation. Thus, using this orthosis needs not to consider fracture or fatigue failure.

We used a 3D printer (UP Box, Go Hot Technologies Co., Ltd, Taiwan) to produce this device. The printing parameters included a layer thickness of 0.2 mm, infill of 70% and printing temperature of 200°C. It took approximately 7 hours to print a "shark fin"-shaped device using polylactic acid (PLA), a biodegradable thermoplastic derived from renewable resources such as corn starch or sugarcane. PLA weighted approximately 111 g and the material cost approximately $4 USD.

3. RESULTS

The patient receiving ulnar shortening surgery used this device to stretch for increasing ROM of wrist extension. He applied the device to stretch for 20 minutes for twice-a-week visit, which lasted for 4 months. The active ROM of wrist extension improved from 30° to 50°. The other patient with the right thumb FPL rupture suffered from thumb contracture; the ROMs of the MCP joint and IP joint were 40°–55° and 20°–25°, respectively. After tenolysis surgery, his ROMs of the MCP and IP joints were improved to 10°–35° and 40°–65°, respectively. However, he did not feel enough ROM of the thumb. Following twice-a-week physical therapy for 2 months by applying the device for 20 minutes during every visit, his ROMs of the MCP and IP joints were further increased to 0°–40° and 25°–70°, respectively.

4. DISCUSSION

Static progressive orthosis can progressively change the passive ROM of a joint. An orthosis applies a constant force to gradually stretch the joint and lengthen the tissues over time, resulting in long-term remodeling.[2] Static progressive stretch devices have positive outcomes in treating adhesive capsulitis of the shoulder,[2] stiffness or contracture of the elbow,[3,4,13,14] wrist,[15] hand,[16] and knee.[17,18] The benefits include increasing active ROM and grip strength, along with improvement of the disabilities of the arm, shoulder, and hand scores and patient satisfaction.[5]

Static progressive orthosis mainly includes screws, static lines, hook and loop tapes, gears, and hinges.[1] Orthosis allows progressive changes in ROM of a joint; however, remodeling the structure of orthosis is not required. A patient using orthosis should be able to gradually readjust the tension force. However, fabricating patient-specific static progressive orthosis is a time-consuming task.

Recently, 3D printing in medical applications has expanded rapidly.[12,19–21] Thus, we adopted 3D printing technology to ease orthosis fabrication. Furthermore, we designed a multifunctional and quickly assembled rehabilitation device to meet various clinical applications. As described earlier and demonstrated in Figs. 1–4, static progressive orthosis can be applied to the subjects with contractures of the MCP, IP, and radiocarpal joints.

In this study, we applied this rehabilitation device to stretch the wrist of a subject with a distal radius fracture. The active ROM of wrist extension improved from 30° to 50°. Previously, a patient with wrist stiffness after distal radius fracture was instructed to wear a static progressive device once for 30 minutes/day and then gradationally increasing to 3 times/day.[11,15] The mean time of wearing splinting was 75–88 days.[11,15] We demonstrated that this newly designed device would also improve ROM of the wrist joint only during the physical therapy visits.

For flexor tendon surgery, early passive movement[22] or rehabilitation[23] plays a key role in excellent clinical outcome and low complication rate. A study[7] also indicated that tendons of good integrity after tenolysis should initiate physical therapy immediately and wear a static extension splinting between exercises and at night. Furthermore, a static progressive orthosis may help to increase ROM. In this study, the active ROMs of the patient were 10°–35° in the MCP joint and 40°–65° in the IP joint after tenolysis surgery. After applying this device for 20 minutes in very twice/week visit, lasting for 4 months, the ROMs increased to 0°–40° in the MCP joint and 25°–70° in the IP joints. According to the standard of the American Academy of Orthopaedic Surgeons, the normal ROM of the thumb for the MCP and IP joints are 0°–50° and 20°–80°, respectively. The outcome demonstrated that this device would be beneficial by increasing the range of the MCP and IP joints.

Therapists treating subjects with hand and wrist injuries may be involved in all stages of recovery, from the acute phase to return to daily life. Understanding the specific demands of the patient and respect for the standards of care are imperative to fabricating an effective orthosis. The commercially available orthoses can certainly augment rehabilitation treatment. On the contrary, 3D printing orthosis can provide patient-specific profile unique to each person.[12] Furthermore, the manufacture process via 3D printing has dramatically changed the production methods. As demonstrated, we used an office-based 3D printer to fabricate this static progressive orthosis. In other words, 3D printing technology can make orthoses customized, low-profile, durable, and tolerable to the patients.

There are limitations to this study. First, we have only completed two cases to date. However, since printing this "shark fin"-shaped device, the physical therapist (the first author) is more comfortable handling the hand rehabilitation cases. Moreover, we could gain more experience in using the device as the number of patients increase. Second, we only evaluated these two subjects during the process of physical therapy. Thus, we should further investigate whether the increase in was a transitional effect or a long-time benefit. However, these two subjects did not request another round of physical therapy, which may indicate the prolonged benefit of using the device. Last, this "shark fin"-shaped device is safe and easy to apply. We may have subjects to bring the device home for more intensive therapy in the near future.

In conclusion, according to our preliminary experience, incorporating the "shark fin"-shaped orthosis into hand rehabilitation increased the ROM of wrist extension for a patient with distal radius fracture and improved the ROM of the MCP and IP joints in another patient after tenolysis surgery.

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