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Case Report

Negative Pressure Wound Therapy Incorporating Early Exercise Therapy in Hand Surgery: Bag-type Negative Pressure Wound Therapy

Kenjiro Hasegawa*, Yuzaburo Namba, and Yoshihiro Kimata

Department of Plastic and Reconstructive Surgery, Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences, Okayama 700–8558, Japan

In the postoperative treatment of hand surgery, it is important to start exercise therapy as early as possible. In conventional negative pressure wound therapy, the fingers are immobilized by the film dressing covering the wound and hand, thereby preventing sufficient rehabilitation. Here, we devised a bag-type negative pressure wound therapy that makes it possible to start finger exercises almost immediately, and we applied it to 4 patients: one each with hand burns, symmetrical peripheral gangrene, a crush injury accompanied by extensive skin defects and a fingertip degloving injury. The duration of the bag-type negative pressure wound therapy ranged from three to eight weeks, and good granulation was achieved, so that a skin graft was not required. In addition, particularly in the case of the fingertip degloving injury, good nail regeneration was achieved. Except for the case of symmetrical peripheral gangrene, a good range of joint motion with a percent total active motion (%TAM) of 94.7% or more was achieved. Our therapy was performed by inserting the hand into a sealing bag; sufficient exercise therapy was made possible by expanding the bag during rehabilitation.

Key words: negative pressure wound therapy, early exercise therapy, wound healing, hand surgery

Negative pressure wound therapy is an excellent method for wound healing [1–3], but when it is applied to the hand, where the fingers are immobilized by the dressing materials, sufficient exercise therapy is not possible during the treatment [4, 5]. We therefore devised a bag-type negative pressure wound therapy incorporating early exercise therapy for the fingers using a commercially available sealing bag. In this study, we applied the bag-type negative pressure wound therapy to the treatment of hand burns, symmetrical peripheral gangrene, a crush injury accompanied by extensive skin defects and a fingertip degloving injury, and obtained good results.

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*Corresponding author. Phone:+81–86–223–7214; Fax:+81–86–235–7210
E-mail:k-hase@md.okayama-u.ac.jp (K. Hasegawa)

Materials and Methods

After the wound is fully debrided, it is covered with a hydrophilic polyurethane sponge (Hydrosite; Smith & Nephew, Tokyo, Japan) using a clean procedure. A suction drainage tube (14 Fr gastric tube catheter; Terumo, Tokyo, Japan) is placed on the sponge, and the sponge and the tube are fixed in place with film dressing (Opsite; Smith & Nephew, Tokyo, Japan). At this time, it is important to make a few side holes at the tip of the drainage tube and remove the film on the back of the Hydrosite sponge to which the tube is attached. Even if some of the holes are filled with drainage fluid, suction should be possible

through the other holes.

After the injured hand is placed in a commercially available gas-sterilized sealing bag (Ziploc; Asahi Kasei, Osaka, Japan), the top of the sealing bag is fixed to the forearm with dressing tape (Million Aid; Kyowa, Osaka, Japan) to create a completely sealed condition. If it is attached by winding the tape, a space is formed between the skin and the sealing bag, but this can avoided by using 2 pieces of tape to pinch it from above and below. A slight incision is made to form a hole in one corner of the bag, and the tube is drawn through the hole. The tube should be fixed with a rubber band or tape to prevent leakage of air. The tube is then connected to an aspirator installed in the bedroom at a negative pressure between −15 and −17 kPa. During the finger exercise therapy, aspiration should be stopped to remove the negative pressure, and if necessary, positive pressure should be applied by aeration using a syringe to expand the bag, since it is important that the fingers are able to move freely (Fig. 1). Patients are instructed directly by a physician at the bedside. Aspiration is performed mainly at bedtime and at rest. When the patient goes to the bathroom, has meals, or leaves the room for a short time, the aspiration tube can be locked to allow freedom of movement and less stress for the patient. The Hydrosite sponge and sealing bag are usually changed once or twice a week.

Evaluation of the postoperative range of finger joint motion is based on the percent total active motion (%TAM) [6, 7]. This is the proportion of TAM [8] of the injured finger compared with the healthy side.

Case Examples

Case 1 was a 5-year-old female child, whose right middle finger was caught in a fruit-sorting machine. She experienced a degloving injury of Type IV in the Allen classification [9], and the apex of the distal phalanx was exposed. Flexion and extension of DIP were possible (Fig. 2A). Since the cut finger was lost, replantation was not an option, and bag-type negative pressure wound therapy incorporating early exercise therapy for the fingers was started on the day of the injury (Fig. 2B). At 34 days after the start of therapy, sufficient granulation and reduction of the wound were achieved, and the therapy was terminated. At 1 week after the completion of therapy, the wound had nearly epithelialized, and at the time of the most recent follow-up, 1 year and 8 months after the completion of therapy, the %TAM was 100%, and the static two-point discrimination (2PD) was 3 mm. The formation of the finger pad was good, and the course of nail regeneration was also favorable, although the size of the nail was smaller than that of the healthy

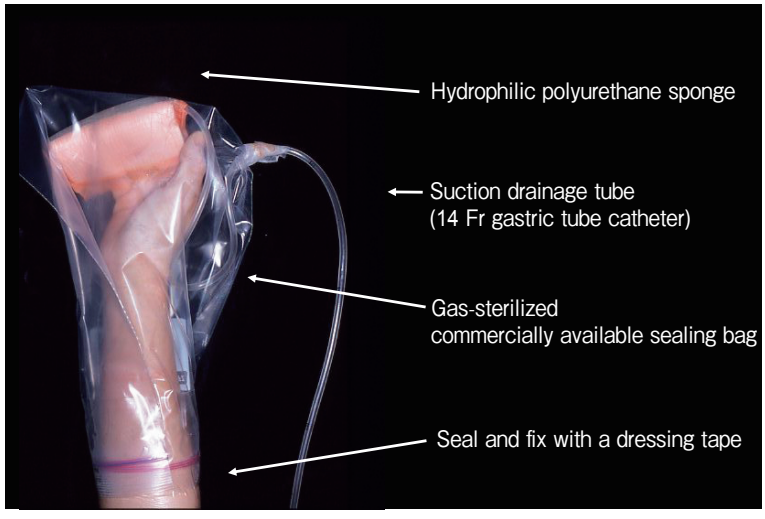

Fig. 1 Bag-type negative pressure wound therapy. Aspiration at a negative pressure of −15 to −17 kPa at rest or at bedtime. During exercise therapy for the fingers, negative pressure is removed, positive pressure is applied if necessary, and sufficient active and passive exercise of the fingers is performed as the sealing bag is expanded.

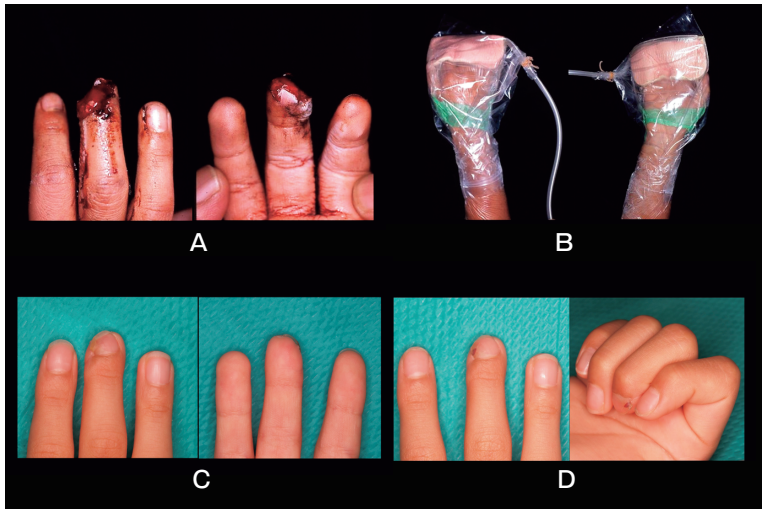

Fig. 2 Case 1: A 5-year-old female child with a degloving injury from catching the right middle finger in a fruit-sorting machine. **A**, at injury, the apex of the distal phalanx was exposed; **B**, on the day of the injury, bag-type negative pressure wound therapy was started; **C**, at 34 weeks after injury, the nail favorably regenerated, although the size was smaller than that of the healthy left middle finger; **D**, at 1 year and 8 months after injury, %TAM was 100%, and static 2PD was 3 mm.

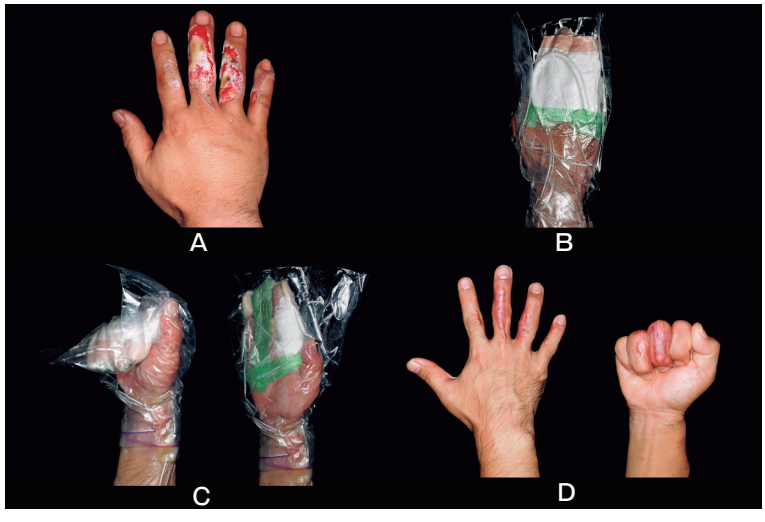

Fig. 3 Case 2: A 38-year-old male with finger burns from a heat press. **A**, at 10 days after injury, negative pressure wound therapy was started; **B**, aspiration at a negative pressure of −15 to −17 kPa (at rest); **C**, aspiration was stopped, negative pressure was removed, and finger exercise was performed (during rehabilitation); **D**, at 17 weeks after injury, %TAM was 97.4% in the middle finger and 94.7% in the ring finger.

left middle finger. She was continuing with her piano lessons (Fig. 2C and D).

Case 2 was a 38-year-old male, whose right fingers were caught in a heat press. The index finger and little finger suffered second-degree superficial dermal burns, and the middle finger and ring finger suffered third-degree deep dermal burns extending to the extensor tendon (Fig. 3A). At 7 days after injury, the patient was referred to the reporting department, and at 10 days after injury, bag-type negative pressure wound therapy was started (Fig. 3B and C). At 8 weeks after the start of therapy, sufficient granulation

and reduction of the wound were achieved, and the therapy was terminated. At 2 weeks after the completion of therapy, the wound had nearly epithelialized. At the time of the most recent follow-up, 17 weeks after injury, the %TAM was 97.4% in the middle finger and 94.7% in the ring finger (Fig. 3D).

Case 3 was a 64-year-old male, whose fingers (index, middle, ring and little fingers) of both hands were necrotized due to severe pneumococcal infection, and he consulted the reporting department 4 months after onset (Fig. 4A). After the patient was diagnosed with symmetrical peripheral gangrene, debridement was performed first on the right necrotized fingers, and bag-type negative pressure wound therapy was started. At 3 weeks after the start of therapy, sufficient granulation and reduction of the wound were achieved, and the therapy was terminated. At 1 week after the completion of therapy, the wound had nearly epithelialized. At the time of the most recent follow-up, 89 and 67 days after the completion of therapy for the right and left hands, respectively, the patient could use a pencil with both hands and make a power grip (Fig. 4BCD).

Case 4 was a 6-year-old female child, whose right hand was run over by a car tire. She suffered a crush wound accompanied by defects of the index finger and middle finger (Fig. 5A). On the day of the injury, amputation stump plasty of the index finger and middle finger and suture of the avulsion were performed (Fig. 5B-1). At 3 weeks after these procedures, the necrotized skin was debrided (Fig. 5B-2), and bag-type negative pressure wound therapy was started. At 3 weeks after the start of therapy, sufficient granulation and reduction of the wound were achieved, and the therapy was terminated. At 1 week after the completion of therapy, the wound had nearly epithelialized. At the time of the most recent follow-up, 50 days after the completion of therapy, the %TAM was 98.1% in the ring finger and 100% in the little finger (Fig. 5C and D).

Discussion

The negative pressure wound control method was first reported as "vacuum sealing" by Fleischmann *et al.* in 1993 [1]. In 1997, Morykwas [2] and Argenta *et al.* [3] presented "vacuum-assisted closure" as a computerized method to adjust the negative pressure. The action mechanism of the therapy is considered to be the following: decreased bacterial count and increased tissue oxygen concentration are induced by the removal of excessive intercellular fluid and improvement of circulation in the wound and surrounding area, thus promoting good granulation and wound healing [2, 3]. The increased proportion of granulation tissues has been shown to be higher under intermittent negative pressure than under continuous negative pressure [2], and with regard to the aspiration pressure, it was

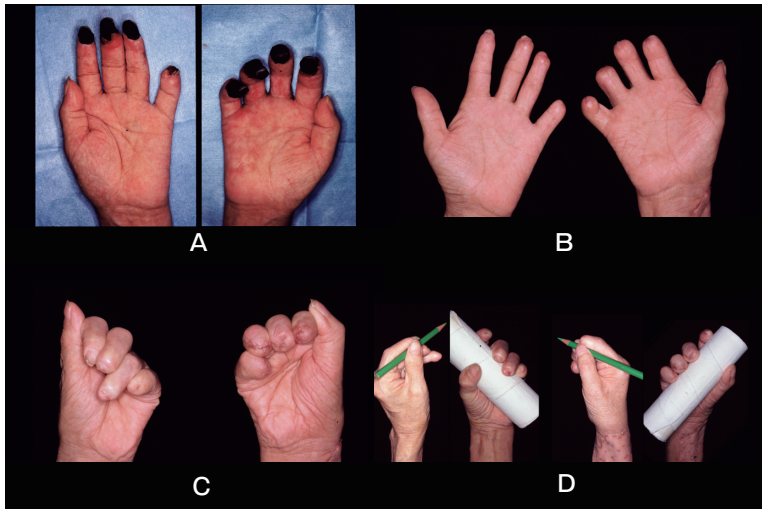

Fig. 4 Case 3: A 64-year-old male whose fingers of both hands were necrotized due to severe infection. **A**, at consultation; **B**, **C**, **D**: 1) at 67 days after completion of negative pressure wound therapy (left-hand fingers). 2) at 89 days after completion of negative pressure wound therapy (right-hand fingers).

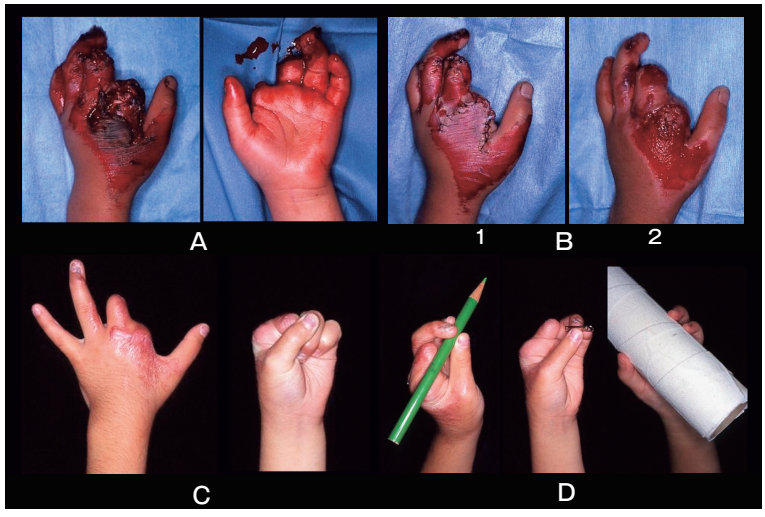

Fig. 5 A 6-year-old female child with a crush wound to her right hand, which was run over by a car tire. **A**, at injury (at the clinical visit); **B**, 1) on the day of the injury (after suture) 2) at 42 days after injury (start of negative pressure wound therapy); **C**, at 50 days after completion of negative pressure wound therapy; **D**, activities of daily living 50 days after completion of negative pressure wound therapy.

reported in animal experiments that granulation was optimum at −125 mmHg (−15 to −17 kPa) [10], which is the setting most widely used now.

Vacuum-assisted closure has also been applied to soft tissue defects associated with sternal osteomyelitis and open fracture [11] in addition to chronic skin ulcers such as decubitus [3].

In hand surgery, negative pressure wound therapy is used in patients with soft tissue defects associated with trauma [12], injury to the fingertips [13, 14], burns [15], and infection [16, 17], and favorable results have been obtained even in patients whose bones, tendons, and nerves were exposed. We believe that our bag-type negative pressure wound therapy has the same indications.

When negative pressure wound therapy is applied to the hand, air is easily leaked due to the complex shape of the hand [4]; thus, a commercially available VAC hand dressing (V.A.C. GranuFoam Hand Dressing; Kinetic Concepts Inc., San Antonio, TX, USA) is used [18]. However, because the hand is placed in a form-fitting sponge, which is fixed with adhesive film dressing, finger movement is restricted, preventing the patient from performing a sufficient range of joint motion exercises during use of the sponge [4, 5]. Therefore, a "hand-in-glove" technique was developed so that training for the range of joint motion can be conducted [4, 5]. In this method, the hand is covered with a copolymer sterile examination glove instead of adhesive film dressing. This technique partially enabled active mobilization of the hand even during the negative pressure wound therapy. However, as the exercise therapy is conducted while the fingers are in the copolymer glove, the results are limited. Also, the exercise motion created a hole in the copolymer glove, which was a cause of air leakage [5]. At this time, we devised a negative pressure wound therapy (bag-type negative pressure wound therapy), which enabled hand exercise therapy not by using a glove, but by using a commercially available sealing bag sufficiently larger than the size of the hand. The negative pressure wound therapy was performed at rest and at bedtime, and during the exercise therapy, negative pressure was removed, and if necessary, positive pressure was applied by aeration using a syringe to expand the sealing bag to larger than the size of the hand to allow active and passive exercise of the hand under the condition that the effects of the bag on the fingers are removed. In this way, since the exercise therapy can be performed at the start of the negative pressure wound therapy, joint stiffness and cicatricial contracture of the fingers could be minimized. In addition, air leakage has rarely been observed when withdrawing the suction tube from the tip of the bag.

The disadvantage of the bag-type negative pressure

wound therapy is that the method aims at the range of joint motion exercise in the early phase, which is not appropriate for free skin graft fixation [15] and functional splinting [12].

Range of joint motion exercise is rehabilitation performed under the condition that the patient places the injured hand in the bag and is currently conducted under the instruction of physicians, but we believe that the rehabilitation can be conducted with the help of physiotherapists and occupational therapists in the future.

Regarding further application of the therapy, since its concomitant use with continuous irrigation has been reported [13], we believe that our bag-type negative pressure wound therapy can also be conducted with continuous irrigation. At present, a commercially available sealing bag is used, but the development of a special bag for bag-type negative pressure wound therapy equipped with an inlet for the aspiration tube is desired.

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