Origianl Article

New Alternative Therapeutic Strategy for Gustilo Type IIIB Open Fractures, Using an Intra-Wound Continuous Negative Pressure Irrigation Treatment System

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Summary: The treatment of Gustilo type IIIB and IIIC open fractures remains a challenging problem, because the infection rate is 15-45%. Infection can lead to serious complications such as osteomyelitis or amputation. The intra-wound continuous negative pressure and irrigation treatment (IW-CONPIT) was developed for infected wounds and intractable ulcers, and is very effective in suppressing infection and accelerating wound healing. Here the IW-CONPIT was applied to severe open fractures for the purpose of preventing infection. After thorough debridement and lavage of the wound, bony stabilization is performed by external fixation. Dermal matrix is grafted onto any areas where the bone or tendon is exposed. A sponge containing two tubes is placed over the entire surface of the wound including the dermal matrix. Then it is covered with a film dressing to make the wound completely airtight. A bottle of physiologic saline solution is attached to one tube, and a continuous aspirator is attached to the other. This system maintains negative pressure on the wound surface, which is continuously irrigated. Thirty-five patients were treated with this method. A superficial infection developed in two cases but was resolved by additional debridement and continued application of IW-CONPIT. Complete wound healing was obtained with split thickness skin graft in all cases. There were no complications such as osteomyelitis, delayed bone union or amputation. IW-CONPIT was able to definitively prevent wound infection in Gustilo type IIIB open fractures. We believe this method will become a standard treatment option for this condition.

Key words Gustilo type IIIB, open fractures, intra-wound continuous negative pressure and irrigation treatment, external fixation, dermal matrix, wound healing, infection, emergent operation

INTRODUCTION

Infection is a crucial problem when treating open fractures with skin and soft tissue defects (Gustilo type IIIB and IIIC) [1-4]. Infection, besides delaying bone union, can lead to serious complications such as osteomyelitis or amputation. Successful treatment depends on whether infection can be controlled or not. Many of the infections that develop after open fractures are nosocomially acquired [5]. For this reason, early coverage of skin and soft tissue defects after radical debridement, irrigation and definitive fixation of the fractures is recommended [6-11]. However,
early coverage, mainly with free flaps, requires personnel capable of performing these procedures, an institution with the facilities for emergency care, and costly and time-consuming operations, not to mention donor-site morbidity, and approximately 10% flap failure rates [6,7,11,12]. And there may be problems achieving coverage of the devitalized soft tissue or with wound contamination because it is very difficult to judge whether debridement has been adequate in the early phase of injury. Therefore, the infection rate for Gustilo type IIIB fractures is near 15~20%, even with emergency treatment or early coverage [6,10,13].

Negative pressure wound therapy (NPWT) created using the vacuum-assisted closure (VAC) system® (Kinetic Concepts Inc, San Antonio, TX) has recently been applied to the treatment of high-energy soft tissue injury associated with open fractures [13-18]. While this therapy significantly decreases edema of the injured extremities and promotes wound healing with healthy granulation tissue, it also has the benefit of protecting the wound from nosocomial infection since the wound is sealed until definitive coverage can be obtained [14]. Application of this therapy decreases the need for a free flap in many Gustilo type IIIB fractures because granulation tissue is rapidly produced over the exposed bone, tendon, and hardware if the exposed area is relatively small [13-15,17]. However, the infection rate in Gustilo type IIIB open fractures has remained high, (15% [13] and 45.8% [17]) despite the utilization of NPWT.

The present authors have developed a method known as Intra-Wound Continuous Negative Pressure Irrigation Treatment (IW-CONPIT), which simultaneously applies continuous negative pressure and irrigation to the infected wound [19]. The method has proven to be extremely effective for the treatment of infections associated with intractable ulcers and postoperative wound infection such as abdominal wall infection following laparotomy and mediastinitis following vascular surgery [19]. The authors applied this method to the treatment of thirty-five cases of Gustilo type IIIB and III C open fractures, not for the purposes of treating infection, but to prevent infection while also promoting early wound bed preparation. This is a report demonstrating the efficacy of the new treatment for severe open fractures.

PATIENTS AND METHODS
Informed consent to undergo IW-CONPIT was obtained from all patients. The study was conducted according to the principles of the Declaration of Helsinki and its revisions and approved by the Institutional Review Board of Kurume University Hospital (approval number, 17324).

The case series consisted of all consecutive patients from April in 2006 to December in 2012 who were diagnosed with Gustilo type III B open fractures.

IW-CONPIT METHOD
Thorough debridement and copious irrigation of

Fig. 1. Application of Intra-Wound Continuous Negative Pressure Irrigation Treatment (IW-CONPIT) to Gustilo type III B open fractures. (a) Tube for suction, (b) Polyethylene film, (c) Sponge, (d) Tube for drawing saline solution, (e) Skin, (f) Subcutaneous soft tissue, (g) Dermal matrix with numerous small perforations, (h) Bone, (i) Muscle.
The wound are performed on the day of the injury. In debridement, ablate all debris, devitalized soft tissue and bone fragments that have become completely deprived of blood circulation. Fractures are managed with external fixation by orthopedic surgeons. As a general rule, avoid the use of plates, screws and intramedullary nails for internal fixation since there is the risk that they may promote infection. Following bony stabilization, it is very important to suture the wound without tension of the flap. If the wound is sutured tightly, blood flow to the tissue is impeded. Where possible, skin and muscle flaps should also be used to cover exposed bone and tendon, but where this is not possible, use a dermal matrix graft (Pelnae®; Gunze, Ltd., Kyoto, Japan; Integra®; Integra LifeSciences, Plainsboro, N.J., USA). When using dermal matrix, use a scalpel to make numerous small perforations in the graft to enable drainage of the wound surface. Cover the entire wound surface, including the dermal matrix, with a sponge, and place two tubes inside the sponge. Then, cover the whole wound area, including the sponge and, if used, the pins of the external fixation device, with polyethylene film so that the inside of the wound becomes completely airtight (Figure 1). One of the tubes is then connected to a bottle containing physiological saline solution while the other tube is connected to a continuous aspirator (Mera Sacume MS-008; Izumi Kokakogyo Co., Ltd.) and irrigation and aspiration are begun. Aspiration is performed with suction pressure maintained at ≈50 cm H2O, the maximum possible with the Mera Sacume®, and the wound is irrigated with 2,000 to 5,000 ml of saline solution per day. It is vital that the bottle of saline solution is kept at the same height as the wound to avoid subjecting the wound to positive pressure (Figure 2). This suction pressure maintains a constant negative pressure inside the wound and draws in saline solution through the sponge to continuously irrigate and cleanse the wound.

The dressing is changed two or three times per week. Debridement and necrotomy are performed at this time, if needed, and additional dermal matrix is grafted if bone or tendons which had been covered with the dermal matrix become partially exposed. Adjust the volume of saline solution used for irrigation depending on the condition of the wound. If infection is not observed on the wound surface, irrigation with 2,000 ml of saline solution per day is sufficient. Conversely, if there is any sign of even the slightest infection in the wound, irrigation with 3,000 to 5,000 ml of

| Age (yr)/ Sex | Lesion                | Initial Bony Fixation | Period to D.S.C. (day) | Means of D.S.C. | Infection | Complications or Additional Treatments                  |
|--------------|-----------------------|-----------------------|------------------------|-----------------|-----------|--------------------------------------------------------|
| 20/M foot    | Pinning               | 15                    | STSG                   | None            | Epidermal necrosis in the flap                          |
| 37/M Tibia/D | Pinning               | 6                     | flap                   | None            | None                                                |
| 33/M Tibia/S | EF                    | 31                    | STSG                   | None            | Residual necrosis in the wound                         |
| 36/M Tibia/S | EF                    | 99                    | STSG                   | None            | None                                                |
| 39/F Hand    | Pinning               | 5                     | flap                   | None            | None                                                |
| 7/F Tibia/Fibula/D | Pinning   | 37                    | STSG                   | None            | None                                                |
| 20/M Tibia/D | Pinning               | 21                    | STSG                   | None            | Secondary plate fixation                               |
| 86/F Tibia/Fibula/S | EF        | 12                    | flap                   | None            | Residual necrosis in the wound                         |
| 17/M Tibia/S | EF                    | 42                    | STSG                   | None            | Residual necrosis in the wound                         |
| 71/M Radius/P | Pinning             | 18                    | Flap                   | None            | None                                                |
| 22/M Tibia/S | EF & Pinning          | 14                    | STSG                   | None            | None                                                |
| 65/M Foot    | Pinning               | 30                    | Flap                   | None            | None                                                |
| 82/F Femur/D | EF                    | 9                     | Flap                   | None            | None                                                |
| 62/M Radius/Ulna/S | EF     | 33                    | STSG                   | None            | Secondary plate fixation                               |
| 83/M Patella | Pinning               | 283                   | STSG                   | Osteomyelitis   | Debridement of the sequetrum                          |
| 65/M Tibia/S | EF                    | 33                    | STSG                   | None            | None                                                |
| 83/F Tibia/S | EF                    | 42                    | STSG                   | None            | None                                                |

P; proximal, S; shaft, D; distal, EF; external fixation, D.S.C.; definitive soft-tissue coverage, STSG; split thickness skin graft, DM; diabetes mellitus
saline solution per day and additional meticulous debridement should be performed. Any air leakage must be carefully avoided, because air leakage makes it impossible to maintain negative pressure, and causes external air containing bacteria to be continuously drawn into the wound, which could lead to infection.

When the healthy granulation has formed all over the wound, split thickness skin grafts (STSG) are performed as definitive coverage. In many cases, exposed bone and tendons become covered with healthy granulation within approximately three to six weeks. Local flaps or free flaps may be attached, if necessary.

RESULTS

In total, thirty-five patients with Gustilo type IIIB and IIIC open fractures underwent IW-CONPIT during the study period. IW-CONPIT was applied to the open wounds from the day of injury and was continued until the day of definitive soft-tissue coverage. The periods from the day of injury to the day of definitive soft-tissue coverage ranged from fifteen days to fifty-nine days (average, 33.8 days) (Table 1). Healthy granulation was formed over the entire area of skin and soft tissue defect, including areas with exposed bone and tendon, at the day of definitive coverage, and complete wound healing was obtained with only split thickness skin grafts in all cases. In one case of a femur fracture by a high-energy injury, a long period of 59 days was required to obtain definitive soft-tissue coverage, because necrosis in a deep area of the wound required us to perform gradual debridement at the bedside. In two other cases complicated by extensive degloving injuries around the Gustilo type IIIB open fractures, superficial infections were observed. It was thought that inflow of external air due to air leakage caused those infections. Infections were, however, suppressed and definitive coverage with split thickness skin grafts was obtained after 56 and 42 days, respectively, after continuously implementing this treatment while performing careful debridement and maintaining airtight status after each dressing change. There was no osteomyelitis and delayed bone union or amputation due to deep infection in any cases. Satisfactory functional results were also obtained.

CASE PRESENTATION

Case 1: A 7-year-old female presented with an open fracture and dislocation of the left distal tibia and fibula, contaminated crush wound, and extensive skin and soft tissue defect associated with exposed bone from the left ankle to the dorsum of the foot resulting from a traffic accident (Figure 3, above, left and middle). An emergency operation was performed under general anesthesia on the same day as the accident. After plastic surgeons conducted thorough debridement and lavage procedures, the fracture was reconstructed and fixed with transdermal pinning by orthopedic surgeons. The torn skin and soft tissue of the ankle were sutured with as little tension as possible by plastic surgeons. Dermal matrix (Pelna®; Gunze, Ltd., Kyoto, Japan) was used to cover extensive areas of exposed anklebone. IW-CONPIT was then applied to the whole wound. The dressing was changed twice per week. Dermal matrix was grafted on the area of exposed bone where no granulation was observed three times when changing the dressing (Fig 3, above, right and below, left). No infection occurred in the wound, which became covered with healthy granulation, including the areas of exposed bone (Fig 3, below, middle). The authors performed a split thickness skin graft with skin from the scalp to cover the skin defect on post-injury day 33. The skin graft completely epithelialized the wound, and the patient was able to return home in the second post-injury month. It is currently 4 years 4 months since the patient was injured and no problems with the wound have been observed (Fig. 3, below, right). Impaired dorsal flexion of the left ankle is observable, but the patient can walk sufficiently with the aid of an ankle-foot orthosis. The patient is currently taking judo lessons. Donor site sacrifice was minimal, and the scar on the head is not noticeable.

Case 2: An 83-year-old female presented with an open fracture of the right tibia and fibula, contaminated crush wound and loss of the right lower leg skin and soft-tissue resulting in partial exposure of the bone fracture site resulting from a traffic accident (Fig. 4, above, left and middle). An emergency operation was performed under general anesthesia on the same day as the accident. After thorough debridement and sufficient lavage of the wound, external fixation was performed for the fractured tibia. The muscle was repaired as much as possible, and dermal matrix (Pelna®; Gunze, Ltd., Kyoto, Japan) was used to cover the exposed bone. IW-CONPIT was then applied to the whole wound, including dermal matrix and pins of the external fixation device. The sponge was changed twice per week. Four additional grafts were applied using dermal matrix for areas of the exposed tibia observed when changing the sponge. No infection occurred in the wound, which became gradu-
Fig. 2. IW-CONPIT for a Gustilo IIIB open fracture. The bottle of saline solution is kept at the same height as the wound to avoid subjecting the wound to positive pressure.

Fig. 3. Case 1. (Above, left) Gross appearance at the day of injury. Debris such as fine sand contaminates the wound. (Above, middle) Radiographic finding at the day of injury. (Above, right) Appearance at the seventh day after injury. The bone is exposed partly. (Below, left) Dermal matrix is grafted on the partially exposed bone on the tenth day after injury. Numerous small perforations must be made in the dermal matrix with a scalpel to enable drainage of the wound surface. (Below, middle) Healthy granulation tissue covering exposed bone on the 33rd day after injury. Split thickness skin graft with skin from the scalp was performed on that day. (Below, right) Findings at 3 year 5 months after injury.

Fig. 4. Case 2. (Above, left) Gross appearance at the day of injury. (Above, middle) Radiographic finding at the day of injury. (Above, right) The bone was still partly exposed at the twelfth day after injury. Additional grafting of the dermal matrix was performed. (Below, left) Healthy granulation tissue covers the entire wound on the 37th day after the injury. A split thickness skin graft was applied at the 42nd day after the injury. (Below, middle) Findings at 10 months after the injury. The patient can walk with a cane. (Below, right) Radiography at 10 months after the injury showed complete bone union.

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ally covered with healthy granulation, including areas of the exposed fractured tibia, and wound area decreased (Fig. 4, above, right and below, left). A split thickness skin graft with skin from the medial side of the right thigh was performed on the 42nd day after the injury. The postoperative course was favorable and the patient began rehabilitation three months after the injury. The external fixation device was removed six months after the injury. At present, ten months after the injury, she can walk with a cane and complete bone union has been obtained (Fig. 4, below, middle and right).

DISCUSSION

Emergency or early coverage, namely the “fix and flap” procedure recommended by Godina [6] and Gopal et al [10] may be an ideal treatment of Gustilo type III B fractures, if orthopedic surgeons and reconstructive microsurgeons competent at these procedures, and institutions equipped with the high level facilities necessary for emergency operations are available, but such is not always the case. Furthermore, emergency or early coverage involves several difficult problems. The wound often has massive contamination and the range of necrosis often expands with time in cases of high-energy soft tissue injury. Therefore, it is difficult to judge whether irrigation and debridement is sufficient to perform definitive coverage of the wound. Severe infection might develop inside the wound if the judgment is incorrect. Determining the range of debridement and the timing of coverage with a free flap or other local flaps requires extremely experienced surgeons. Moreover, coverage using a free flap also entails considerable donor-site morbidity and a risk of total flap loss. The flap failure rate ranges from 3.5% to 11.1%, which is higher than that of reconstructive surgeries in other sites [6, 7, 10-13, 17].

NPWT has been applied for the treatment of high-energy soft tissue injury associated with open fractures as a bridge to definitive coverage [13-18]. NPWT has the benefits of decreasing edema, isolating the wound from the outside environment, and promoting granulation of the wound [14]. The application of NPWT decreases the need for a free flap in many Gustilo type III B fractures and increases the percentage of cases in which the wound is finally closed with split thickness skin grafts [13-15, 17]. However, some studies reported the infection rate in Gustilo type III B open fractures remained as high as 15% [13] and 45.8% [17] despite the application of NPWT. On the other hand, another study has suggesting that patients treated with NPWT were only one-fifth as likely to have an infection compared with patients randomized to the control group treated with standard fine mesh gauze dressing until wound closure [18]. They reported the infection rate for patients treated with NPWT was 5.4%. The reason for their low infection rate compared with the former studies might be a much shorter time interval to definitive coverage (3.5 days compared with 7 [13] and 12.7[17] days). In any case, the application of NPWT is difficult once infection occurs within a wound. Several studies [20-22] reported NPWT could not successfully reduce bacterial load within the wound, and NPWT cannot clinically suppress wound infection [19, 23]. Most Gustilo type III B open fractures are massively contaminated wounds. NPWT can prevent nosocomial infections, but cannot prevent infection that occurs within the contaminated wound. If infection has already developed, then performing a lavage procedure once or twice a day does not sufficiently clean the wound because bacteria rapidly proliferate and reach their original number [24]. The most effective treatment to suppress infection is continuous irrigation. In view of this situation, we developed a method known as Intra-Wound Continuous Negative Pressure Irrigation Treatment (IW-CONPIT) based on the VAC system and the continuous irrigation method [18]. In our new method for the treatment of Gustilo type III B open fractures, rather than using the IW-CONPIT to suppress infection that has already developed, it was used to prevent infection. This procedure has the following additional advantages: 1. Any surgeon anywhere can easily perform this procedure, which is practically non-invasive. 2. Because the skin wound is not closed at an early stage, there is no risk of sources of infection remaining in the wound, and follow-up debridement of necrotic skin and soft tissue can be performed. 3. Continuous negative pressure prevents the formation of a dead space around bone and tendon. 4. Even if there is exposed bone and tendon associated with the skin wound, complete recovery can be obtained with a simple, extremely non-invasive procedure using dermal matrix grafts. 5. The method can be used to control infection and thereby save time until the patient is transferred to a better-equipped institution. 6. It is possible to apply this method to the wound where infection has already developed. 7. This method allows a definite decision to be reached on the safe timing for treatment with a free flap if necessary in cases where a bone defect is observed due to extensive loss of skin and soft-tissue. On the other hand, the disadvantages of this method are that it requires a longer time interval to achieve de-
CONCLUSION

We believe this method will become a standard treatment option for Gustilo type IIIb open fractures and could potentially save many injured people from the worst case scenario of either sepsis or limb amputation.

CONFLICT OF INTEREST: INSTITUTIONAL AFFILIATION: None. Disclosure: None of the authors has a financial interest in any of the products or devices mentioned in this article.

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