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Management of open fracture and related complications: the Japanese way

Hiroaki Minehara, MD[a,*], Yukichi Zenke, MD[b], Akihiro Maruo, MD[c], Takashi Matsushita, MD[a], Theodore Miclau III, MD[d]

Abstract Open fractures continue to be a challenging clinical problem throughout the world, and Japan is no exception. Surgeons are faced with critical decisions throughout the care of these injuries that can have significant effects in clinical outcome, ranging from the type and timing of antibiotic administration, fixation, soft-tissue management, and interventions for postfracture complications. In October 2022, the Japanese Society for Fracture Repair (JSFR) was invited to represent Japan as the Guest Nation society at the 38th Annual Meeting of the Orthopaedic Trauma Society held in Tampa, Florida. The JSFR organized a symposium, entitled "Management of Open Fracture and related complications—the Japanese way," that featured cutting-edge approaches to open fractures in their country, including presentations on the "fix-and-flap" approach, local antibiotics perfusion delivery, and a "chipping" method for the stimulation of bone healing. This article summarizes the content of these 3 presentations from that symposium.

Keywords: open fracture, fix and flap, CLAP (continuous local antibiotics perfusion), posttraumatic infection, nonunion, deformity correction, chipping technique

1. Introduction

The treatment of severe open fractures remains challenging for orthopaedic trauma surgeons. Decision making throughout the process can profoundly affect the outcome of these injuries, including the type and timing of antibiotic administration, fixation, soft-tissue management, and interventions for post-fracture complications. Complications that include healing impairment, infection, and deformity are often difficult to treat and can result in long-term disability with loss of limb function or amputation. Improvements to diminish the risk of these debilitating complications continue to be developed.

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Any investigation involving human subjects or the use of patient data for research purposes was approved by the committee on research ethics at the institution in which the research was conducted in accordance with the Declaration of the World Medical Association.

2. Severe Open Fracture Fix-and-Flap Method as Japan's Strategy

Open limb fractures with severe soft-tissue injuries are often difficult to treat, requiring not only treatment of the fracture but also the surrounding soft tissues, nerves, and blood vessels. Effective management of these injuries involves close collaboration with plastic surgeons in general as key, although in Japan, the philosophy behind the type and timing of soft-tissue management between orthopaedic and plastic surgery teams can differ substantially. Currently in Japan, there is support for providing the full scope of necessary care for severe open fractures within

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[a] Department of Traumatology, Fukushima Medical University, Trauma and Reconstruction Center, Shin-Yurigaoka General Hospital, Kawasaki, Japan, [b] Trauma Reconstruction Center, University of Occupational and Environmental Health, Kitakyushu, Japan, [c] Department of Orthopaedic Surgery, Harima-Himeji General Medical Center, Himeji, Japan, [d] Department of Orthopaedic Surgery, Orthopaedic Trauma Institute, University of California, San Francisco, School of Medicine, Zuckerberg San Francisco General Hospital, San Francisco, CA

* Corresponding author. Address: Department of Traumatology, Fukushima Medical University, Trauma and Reconstruction Center, Shin-Yurigaoka General Hospital, Kawasaki 215-0026, Japan. E-mail address: jpminet@aol.com (H. Minehara).

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the orthopaedic department, with some institutions focusing on training orthoplastic trauma surgeons. The goal is for surgeons to have the ability to systematically execute a patient's care throughout the entire process, from initial to reconstructive surgery, based on an orthoplastic approach. Although definitive fracture fixation and subsequent soft-tissue coverage ideally occurs within the first several days after injury, many practical obstacles exist. This section describes a fix-and-flap method used in Japan for treating severe extremity trauma.

2.1. Standard of Care in Severe Extremity Trauma

The treatment of severe open fractures may appear routine, but not every surgeon has the training to adequately manage these injuries or achieve results within the "standard of care with a deviation of 60." In 1991, the British Orthopaedic Association and the Society of Plastic and Reconstructive Surgeons held their first meeting to develop "Guidelines for the Treatment of Open Fractures." The "British Manual of Open Fractures"[1] was published in 2009 and the "Standard Treatment of Severe Limb Trauma"[2] was published in Japan in 2017, both of which have influenced the treatment of these injuries. However, relative to some other regions globally, the frequency of this trauma is less common, occurring in only one in several tens of thousands of people per year. This less frequent incidence complicates the formation of teams and protocols, contributing to a lag in the establishment of trauma reconstruction centers and the development of collaborative specialist approaches.

2.2. Importance of Initial Treatment

The outcome of trauma treatment is affected by both the injury and competence of the initial care physician. In the current situation in Japan, where severe extremity trauma cases are not consolidated, young inexperienced physicians may provide initial treatment in general hospitals practicing emergency medicine. The keywords in initial treatment are "early administration of antimicrobials," "cleaning and debridement," and "early stabilization of the bone." While it might seem easy to understand these concepts from a textbook or guidance from specialists and put them into practice, the fact that they are not universally practiced is the reality of severe limb trauma care in Japan. To address this issue, a seminar called Japan Severe Extremity Symposium (commonly known as JSETS) has been led by Dr. Yoshihiko Tsuchida and held once a year since 2009 to raise awareness of knowledge and techniques for open fracture care. There is an urgent need to establish trauma reconstruction centers for each region of Japan in the future.

2.3. The Big 5 in Open Fracture Care

The big 5 in open fracture care in Japan are (1) "treat as an emergency"; (2) "early antimicrobial administration"; (3) "appropriate debridement and redebridement"; (4) "stabilize the fracture and soft tissue"; and (5) "early soft-tissue closure, fix, and flap."

Of these, (3) and (5) will be discussed further below.

2.3.1. Debridement and Redebridement: Step-by-step Approach. Debridement is a critical technique and should be practiced as a standardized procedure so that the same results can be obtained at all facilities as much as possible. The key points of the technique are shallow to deep, skin to fat and fascia to muscle to bone, and wound margin to center. Redebridement is necessary to delineate tissue viability, which can be difficult to achieve. In general, the more severe the contamination or injury, the earlier the second look surgery must be performed, with a goal to perform redebridement within 24 to 48 hours.

2.3.2. Early Soft-Tissue Closure. Ideally, wound closure should be completed within 72 hours,[3,4] but certainly by one week with soft-tissue reconstruction in the acute phase, before bacterial colonization. There are various types of open fractures with uncoverable soft-tissue defects, specifically Gustilo (G) classification type 3B fractures.[5,6] Tsuchida classified G3B into 4 types according to bone and soft-tissue defects[7]: Group 1: simple fracture type and more significant soft-tissue defect (70%); Group 2: fracture and soft-tissue defect are comparable (5%); Group 3: significant soft-tissue defects and a 6 cm or less of bone defect (20%); and Group 4: significant soft-tissue defects and a 6 cm or more of bone loss (5%).[7] Although it is ideal to perform fix-and-flap procedures at the same time, bone fixation followed by flap placement,[2] in which bone reconstruction is performed as early as possible, followed by soft-tissue reconstruction at a later date while monitoring changes in the soft-tissue defect area is more reliable from the perspective of the current workflow in Japan.

2.4. Team Approaches for the Care of Severe Open Fractures in Japan

In Japan, there are generally 2 types of team approaches for treating mangled extremities. One is the integrated treatment, which is performed solely by orthopaedic surgeons. The other one is the collaborative treatment, which is performed by orthopaedic and plastic surgeons together. The former is ideal, but the latter is more realistic. In Japan, the ratio of the 2 team approaches, that is, treatment by orthopaedics alone versus a collaboration of orthopaedics and plastic surgery, is approximately 25% and 75%, respectively. Some hospitals can perform reconstructive surgery solely through the orthopaedic surgery department, which has the benefit of being able to consistently establish a treatment strategy from initial management to the final follow-up. The case reported by Futamura et al.[8] represented a case in which collaborative treatment would never have been successful. However, unless performed in a highly specialized center, bone reconstruction is usually performed by an orthopaedic surgeon and soft-tissue reconstruction by a plastic surgeon. Therefore, the formation of collaborations among specialists is essential to achieve optimal patient care.

2.5. Considerations for Reconstructive Procedures

It is necessary to be keenly aware of the problems unique to trauma reconstruction. Trauma conditions may change from moment to moment, critical structures (eg, vessels and muscle) necessary for flap reconstruction may also be injured, and there may be complex timing considerations during the course of treatment. Large clinical volumes enhance surgeon expertise and facilitate the development of institutional protocols. Finally, peer review meetings and online learning activities can aid care teams in honing skills for more optimal management of severely injured extremities.

Although the establishment of trauma reconstruction centers has been slow in Japan, some orthopaedic surgeons have the tools to simultaneously perform bone and soft-tissue reconstruction. Future efforts should be made to ensure that orthopaedic trainees have basic skills in the management of both fracture fixation and soft-tissue coverage. Furthermore, health care institutions should create protocols and adopt strategies that provide for the proper environment to perform the necessary fix-and-flap procedures.

3. CLAP for the Treatment of Post-Traumatic Infection

Orthopaedic infections are among the most challenging post-injury complications. Post-traumatic infections are particularly difficult because infection control and fracture healing must be managed simultaneously.[9] In general, there are large "dead spaces" due to hematoma, soft tissue, and bone loss secondary to trauma. Traumatic injuries and orthopaedic implants reduce blood supply at the site of the potential infection. Biofilms are known as bacterial aggregates formed on implant surfaces, foreign bodies, and necrotic tissues. The concentration required to prevent the formation of biofilm, defined as minimum biofilm eradication concentration (MBEC), must be 100 to 1000 times as much as the minimum inhibitory concentrations (MICs)[10] of antibiotics. Intravenous antibiotics administration is most often unable to reach required concentrations at an infection site. Therefore, local antibiotics administration is a useful adjunct for the management of musculoskeletal infections.[9]

Antibiotic-loaded acrylic cements have been used for orthopaedic infections as a local drug delivery system.[11] This approach requires physical space to place the antibiotic carrier, and the antibiotic concentration from the carrier rapidly drops to the MIC level after a few days. In cases of post-traumatic infection, there is often no space to place a carrier, particularly with a retained implant in place. Infection spreads to bone, adjacent joints, and surrounding soft tissues, and it is difficult for carriers to maintain high concentrations throughout the infected area for the required treatment duration.

A CLAP technique was developed for the continuous local drug delivery of antibiotics to bone and soft-tissue infections.[12] The method "intramedullary antibiotic perfusion (iMAP)" provides for antibiotic administration directly to the affected bone marrow. "Intra–soft tissue antibiotic perfusion (iSAP)" delivers antibiotics directly to the soft tissues through a double-lumen tube. Antibiotics can be infused by a sub-lumen tube while hematoma and infused solutions were aspirated by a main tube with connection to the negative-pressure system. Through iMAP and iSAP, antibiotics solutions can be delivered to a target area for a required period for required concentration (Fig. 1).

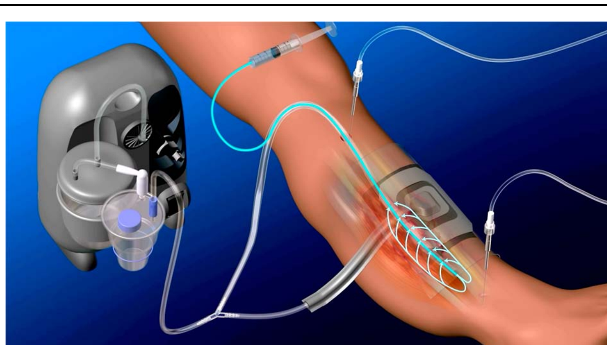

Figure 1. Continuous local antibiotics perfusion (CLAP).

The choice of antibiotics for local delivery is critical. Theoretically, most bactericidal and dose-dependent agents are suitable for local use. According to past reports, high-dose antibiotics suppress multidrug-resistant single microbes and biofilm forms.[13] Gentamicin meets these criteria; it requires relatively low doses to eradicate staphylococci, including multidrug-resistant strains. The target dose for local delivery should exceed the mutant prevention concentration (MPC), which defines the concentration needed to eradicate drug-resistant microbes and MBEC. If the serum concentration does not exceed the trough value during the use of a continuous local delivery system, systemic adverse effects may be avoided. The serum antibiotics concentration should be monitored twice weekly during CLAP therapy. With gentamicin, if the concentration is greater than 1 μg/mL as a trough level,[14] the initial gentamicin concentration should be decreased. 1.2 mg/mL of gentamicin has been reported for use in a standard protocol.[12]

Recently, a case series reported the management of 40 patients with a diagnosis of fracture-related infection (FRI) per the Metsemakers criteria treated with the CLAP technique. According to this report, 87% of the cases had implant retention and 95% had 1 patient developing transient acute renal injury as a systemic side effect, which resolved. Blood concentrations of gentamicin were adjusted to less than the trough level. Fifteen percent of the cases had recurrence of the infection after 3 months of follow-up, all of which had eradication of their infection after CLAP application.[15] It was concluded that the

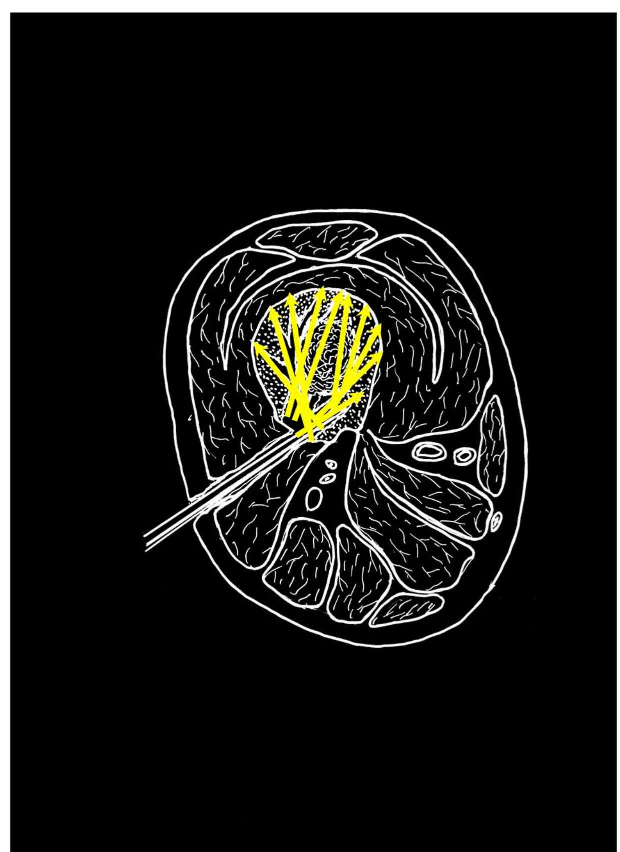

Figure 2. Chipping: The nonunion site must be broken into small pieces up to the intact part of the proximal and distal bone fragments using a sharp osteotome through a small skin incision.

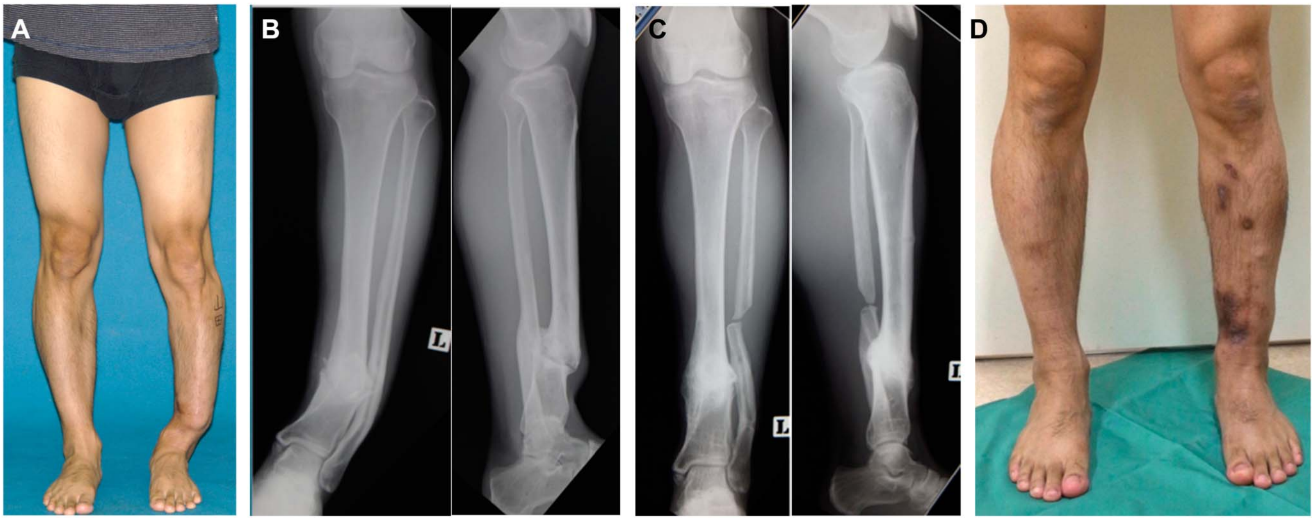

Figure 3. A and B, A 42-year-old man sustained a tibia fracture after a motorcycle accident. Initially treated conservatively, he was referred 5 years after the initial injury (30 degrees of varus, 2 cm of anteroposterior translation, 2 cm of shortening, and nonunion). A Taylor spatial frame (TSF) was applied, and the chipping technique was used. Correction started one week after operation per TSF protocol, with full correction at 5 weeks. C and D, Seven months after operation, the external fixator was removed. At 12 months, the bone was united.

CLAP method can safely deliver antibiotics locally at concentrations as high as the MBEC, which cannot be reached by systemic administration. Furthermore, with the utilization of CLAP, it was possible to eradicate infections with retained implants, with CLAP potentially representing a game-changing therapeutic approach to post-traumatic bone infections.

4. Nonunion and Deformity Correction: The Chipping Technique

Chipping is a technique used to reconstruct nonunion or delayed union without bone grafting by chipping of bone at the original fracture site. Deformity correction can be performed at the chipping site simultaneously, and lengthening can be performed using the callus formed at the chipping site. The chipping technique, which does not require a donor site for bone harvesting, is a useful technique for nonunion and delayed union accompanied by deformities and/or shortening.

4.1. Background

Free bone graft is used widely to treat nonunion. When free bone graft is performed, mesenchymal stem cells, cytokines (eg, bone morphogenetic proteins and basic fibroblast growth factors), and other factors are transplanted to the nonunion site. The chipping technique uses those factors that already exist in the adjacent bone, avoiding the need for an additional donor site. When chipping is performed, the nonunion site is broken into small pieces using a sharp osteotome through a small incision, up to the intact part of the proximal and distal bone fragments to introduce the materials from the intramedullary space to the nonunion site (Fig. 2).[16] The wound should not be irrigated to maintain the bone marrow fluid at the chipping site and promote callus formation.

4.2. Clinical Results

Between 1997 and 2019, the chipping technique was applied to 72 lower extremities, 44 femoral nonunion and 28 tibial nonunion. Among the 72 cases, 67 healed with one chipping surgery. The other 5 cases required a second chipping procedure and finally healed successfully without any other procedure. The healing rate after one chipping was 93%, and all the nonunions healed after 1 or 2 chipping procedures, not requiring any additional intervention.

4.3. Discussions

The chipping technique is a combined method of mechanical stimulation for bone healing and osteotomy for bone lengthening.[17,18] (Figs. 3A–D). The method can be used to treat both nonunion and deformity, while maintaining the integrity of the surrounding soft tissues and avoiding donor site complications related to autogenous bone graft harvesting.[19] Chipping represents an additional method in the treatment of nonunion and possesses advantages over standard bone grafting and wedge osteotomy treatments. Furthermore, it can be used to treat nonunion and deformity simultaneously.

5. Conclusion

This report presents new treatment trends for severely injured open fractures in Japan. Although the orthoplastic approach is becoming more prevalent in the treatment and management of soft tissue in open fractures, many Japanese centers still continue to rely on the collaboration between the orthopaedic and plastic surgery services. CLAP (continuous local antibiotic perfusion therapy) and chipping techniques were originally developed in Japan as treatments of difficult complications such as infection, nonunion, and malunion, with demonstrated effectiveness. The hope is that concepts presented in this work will be useful to other surgeons in the treatment of patients with severely injured open fractures in other countries as well.

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