Abstract

Traditionally, closure of open fractures after initial débridement has been delayed to minimize the risk of complications, particularly infection. This practice developed before the widespread use of systemic antibiotics, local antibiotic bead pouches, advanced débridement methods, and improved fracture stabilization techniques. Current evidence indicates that infections after treatment of open fractures frequently are not caused by initial contaminating organisms but often are acquired in the hospital. Recent studies comparing primary with delayed closure have not demonstrated an increased rate of complications. Considering the improvements in open fracture wound care, the increasing incidence of resistant nosocomial infections, and the cost implications of a dogmatic delayed-closure strategy, wound care protocols for open fractures should be reevaluated. Because of lack of data specifically addressing the timing of closure of such wounds, studies comparing primary versus delayed closure are needed.


The widely accepted standard of care in timing the closure of soft-tissue injury associated with open fracture is to leave the traumatic wound open after the initial surgical débridement. However, this practice is based on a philosophy established before the advent of current antibiotics, modern débridement methods, and improved fracture stabilization techniques. Recent studies challenge the concept of leaving all open fracture wounds open after initial débridement.

Historical Perspective

The open fracture care concept is based largely on the experiences of war surgeons, dating back to the pre-asepsis era. Because of the nature of the wounds sustained on the battlefield, Trueta in 1939 advocated the “closed treatment of war fractures.” This referred to open treatment of the wound with subsequent enclosure of the extremity in a plaster-of-paris cast. Trueta was revolutionary in his approach to handling soft-tissue injury associated with open fracture. Contrary to the general opinions held before the Spanish Civil War, he believed that the greatest danger of infection lay not in the bone but in the muscle. He recommended débridement of the wound with excision of bruised tissue. The wound was drained with the use of sterile absorbent gauze and left open to heal by secondary intention. Finally, a plaster cast was applied to the limb. Instead of windowing the cast to allow “full view” of the wound, as was common for the time, Trueta kept the cast in place “unless it became wet and soft, or there was an intolerable stench, or the patient’s condition showed that some complication had developed.”

The method of leaving the wound open persisted until further experience was gained during World War II, a period that produced great advances in the treatment of open wounds. Because of his work with sulfonamides, Domack advocated systemic administration instead of localized application of antibacterial substances. In 1943, use of penicillin on the battlefield quickly reduced the rate of wound sepsis. However, by relying on the antibiotic’s efficiency, surgeons became too complacent with the débridement procedure. Prompted by the complications of inadequately débrided wounds, the concept of delayed closure was adopted. Hampton recommended closure between the fourth and seventh days, provided the wound was clinically clean. Larger defects continued to be left open to heal by the established secondary intention.
This approach to wound management is still advocated by many authors.5-12

Advances in Open Fracture Management

The basic objectives in the management of open fractures are the same today as in the time of Trueta: to prevent infection, achieve bony union, and restore function. During the past half century, however, the development and availability of broad-spectrum antibiotics, antibiotic-impregnated polymethylmethacrylate beads, pulse lavage, and a choice of various fracture stabilization devices have improved standards of treatment. Yet despite the great effectiveness of antibiotics, no principle is more important in the care of an open fracture than aggressive irrigation and débridement. Penetration of antibiotics into necrotic tissue still is under investigation. Theories range from decreased penetrance secondary to an interruption in the blood supply to an increased penetrance related to local inflammatory mediators.13,14 In either case, the use of antibiotics is not a substitute for thorough surgical débridement. Antibiotics are adjuvants best used in conjunction with surgical management.

In a prospective, randomized clinical trial, Patzakis et al15 found that the infection rate decreased sixfold, from 13.9% to 2.3%, when the administration of appropriate antibiotics was compared with placebo. Moehring et al16 prospectively compared antibiotic beads with intravenous antibiotics and found no statistically significant difference in the two delivery methods. Despite these findings, they concluded that “antibiotic beads may be useful in preventing infection in open fractures.” Ostermann et al17 reported a significant decrease in the rate of wound infection with the combined use of systemic antibiotics and an antibiotic bead pouch for grade III B and IIIC fractures (IIIB, 7% for combined treatment versus 41% for systemic antibiotics alone [P < 0.001], and IIIC, 5% versus 25% [P < 0.05]).

The overall infection rate for the systemic antibiotic group was 12%, compared with 3.7% for the combined-treatment group (P < 0.001). In accordance with Moehring et al16 Ostermann et al17 recommended using antibiotic beads in conjunction with conventional intravenous antibiotics.

Jet lavage has been instrumental in removing contaminants from wounds and is clearly an advance in wound therapy. Anglen et al18 found that the use of power irrigation increased the removal of bacteria by a factor of at least 100 over bulb syringe irrigation of the same volume. This was consistent with the findings of Gross et al14 in a study of contaminated crushed muscle in animals, where pulsatile lavage irrigation was compared with that of a bulb syringe. The wounds irrigated with pulsatile-power lavage had fewer bacteria as well as less wound inflammation and debris up to 12 days postoperatively. Necrosis was markedly higher for the wounds treated with bulb syringe up to 6 days postoperatively. Although the threshold volume of irrigation is unknown, the recommended volume is between 3 and 9 L, often based on the severity of the injury (grade I, 3 L; grade II, 6 L; and grade III, 9 L).19 Pressure at the tissue level appears to be the most important determinant in successful decontamination of the wound.20 Increased pressure removes more debris and bacteria; however, higher pressure settings (70 psi) have detrimental effects on bone healing.21 Low- to moderate-pressure settings (15 psi to 25 psi) appear to balance the potential bone-damaging effects with the proven contaminant-clearing properties of jet lavage.22 Investigations are ongoing to develop a new delivery system aimed at optimizing both volume and flow while minimizing the deleterious effects on soft tissue and bone.

Alternatives now exist for fracture stabilization, including external fixators and intramedullary devices, that are marked improvements compared with balanced skeletal traction or cast immobilization. Modern methods of early surgical fixation provide excellent stabilization of the injury zone, early joint range of motion, and a decreased incidence of pulmonary complications in the multiply injured patient.23,24 Rigid fixation also has been shown to promote healing and facilitate rehabilitation.25

Most acute infections after open fractures are caused by pathogens acquired in the hospital.26,27 Gustilo and Anderson28 reported in 1976 that most of the infections (5 of 8) in their prospective study of 326 open fractures developed secondarily. If left open for an extended period (>2 weeks), wounds were prone to nosocomial contaminants such as Pseudomonas species and other gram-negative bacteria. During the past 25 years, it has become increasingly difficult to predict a subsequent infecting pathogen on the basis of initial wound cultures. In a recent study, Patzakis et al29 found that only 18% of infections were caused by the same organism initially isolated in the perioperative cultures, in contrast with a 73% correlation in an earlier study.15 This emergence of hospital-acquired bacteria and their prominent role in the pathogenesis of infection emphasizes the importance of early wound coverage. Considering the potential consequences of having an open wound in the hospital environment, the fracture site and surrounding soft tissue may be cleanest after the initial aggressive débridement and wound irrigation.
Timing of Wound Closure

The literature on open fracture management exhibits wide discrepancies in terminology. Definitions of nonunion/union, osteomyelitis, deep infection, and superficial infection vary considerably. In addition, the Gustilo and Anderson classification, which is used almost universally for open fracture severity, has been shown to have poor interobserver agreement. Thus, comparing results is difficult.

Only a few North American studies have focused on the timing of closure of open fracture wounds (Table 1). In a double-blind prospective study, Benson et al assessed the benefit of delaying primary closure of wounds associated with open fractures. Eighty-two fractures were divided into primary-closure (44 wounds) and delayed-closure (38 wounds) groups a mean of 6 days after injury. Internal fixation was used in 38% of the cases. Only three superficial wound infections were reported; these occurred in the primary-closure wounds. There were

### Table 1

<table>
<thead>
<tr>
<th>Study</th>
<th>Year(s)/Design</th>
<th>Fracture Grade</th>
<th>Wound Closure</th>
<th>Infection Rate (%)</th>
<th>Delayed/Nonunion (%)</th>
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</thead>
<tbody>
<tr>
<td>Gustilo and Anderson 28</td>
<td>1961-1968/Retrospective</td>
<td>III (16/21)</td>
<td>Primary</td>
<td>7/16 (44)</td>
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<td>Gustilo and Anderson 28</td>
<td>1969-1973/Prospective</td>
<td>I (78/326)</td>
<td>Primary</td>
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<td>—</td>
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<td></td>
<td>II (181/326)</td>
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<td>2/181 (1)</td>
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<tr>
<td></td>
<td></td>
<td>III (67/326)</td>
<td>Delayed</td>
<td>6/67 (9)</td>
<td>—</td>
</tr>
<tr>
<td>Caudle and Stern 32</td>
<td>1979-1983/Retrospective</td>
<td>IIIA (11/62)</td>
<td>—</td>
<td>0</td>
<td>3/11 (27)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IIIB* (24/62)</td>
<td>Flap in &lt;1 wk</td>
<td>2/24 (8)</td>
<td>5/22 (23)</td>
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<tr>
<td></td>
<td></td>
<td>IIIB† (18/62)</td>
<td>Flap &gt;1 wk or secondary intent</td>
<td>10/17 (59)</td>
<td>10/13 (77)</td>
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<tr>
<td></td>
<td></td>
<td>IIIC§ (9/62)</td>
<td>—</td>
<td>4/7 (57)</td>
<td>5/5 (100)</td>
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<tr>
<td>Hope and Cole 33</td>
<td>1981-1989/Retrospective</td>
<td>I (22/92)</td>
<td>Primary, 11</td>
<td>0</td>
<td>5/22 (23)</td>
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<td>Primary, 35</td>
<td>6/51 (12)</td>
<td>9/51 (18)</td>
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<td>III (19/92)</td>
<td>Delayed, 14</td>
<td>4/19 (21)</td>
<td>8/19 (42)</td>
</tr>
<tr>
<td>Benson et al 34</td>
<td>1983/Prospective</td>
<td>—‡</td>
<td>Primary, 44</td>
<td>3/44 (7) (all superficial)</td>
<td>—</td>
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<tr>
<td></td>
<td></td>
<td>—§</td>
<td>Delayed, 38</td>
<td>2/38 (5) (all deep)</td>
<td>—</td>
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<td>Cullen et al 35</td>
<td>1983-1993/Retrospective</td>
<td>I (24/83)</td>
<td>Primary, 20</td>
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<td></td>
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<td>Delayed, 4</td>
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<td>Primary, 30</td>
<td>1/30 (3)</td>
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<td>1/7 (14)</td>
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<td>DeLong et al 36</td>
<td>1984-1987/Retrospective</td>
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<td>Primary, 22</td>
<td>0</td>
<td>1/22 (5)</td>
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<td>—</td>
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<tr>
<td></td>
<td></td>
<td>II (43/118)</td>
<td>Primary, 37</td>
<td>2/37 (5)</td>
<td>4/37 (11)</td>
</tr>
<tr>
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<td></td>
<td>—</td>
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<td>2/6 (33)</td>
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<tr>
<td></td>
<td></td>
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<td>Primary, 24</td>
<td>1/24 (4)</td>
<td>4/24 (17)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>—</td>
<td>Delayed, 8</td>
<td>1/8 (13)</td>
<td>2/8 (25)</td>
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<td></td>
<td></td>
<td>IIIB (12/118)</td>
<td>Primary, 4</td>
<td>0</td>
<td>1/4 (25)</td>
</tr>
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<td></td>
<td>—</td>
<td>Delayed, 8</td>
<td>1/8 (13)</td>
<td>3/8 (38)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IIIIC (6/118)</td>
<td>Delayed, 6*</td>
<td>3/6 (50)</td>
<td>2/6 (33)</td>
</tr>
</tbody>
</table>

Secondary amputation required in ‘2/24 (8%), 14/17 (24%), 8/7 (97%), and *1/7 (14%).
‡ One patient required early amputation and was excluded from analysis.
§ Pediatric population.
¶ No grading indicated.
* One additional patient in this series with a grade IIIC fracture and delayed wound closure had a primary below-knee amputation.
two deep wound infections, both in delayed-closure wounds. Statistical analysis revealed infection to be independent of method of closure.

In a retrospective review of 83 pediatric open tibia fractures, Cullen et al. had done primary closure in 57 cases (69%). There were 24 grade I, 40 grade II, 13 grade IIIA, 6 grade IIIB, and no grade IIIC fractures. The type of wound closure was chosen on the basis of soft-tissue injury and wound contamination. Four grade I, 10 grade II, and 12 grade III fractures underwent delayed closure or soft-tissue flap closure. Two of the 57 primarily closed wounds (3.5%) demonstrated a superficial infection, with neither wound progressing to a deep infection or osteomyelitis. Both wounds were grossly contaminated at the time of surgery, and “in retrospect, not suitable for primary wound closure.” The authors supported the use of primary wound closure in the treatment of open fractures in children, with the obvious exceptions being gross contamination of the wound or any concern regarding the adequacy of the débridement.

DeLong et al. in a review of 119 open fracture wounds, sought to determine whether immediate primary closure of open fracture wounds could be done without increasing the incidence of infections and delayed unions or nonunions. All patients received preoperative cefazolin, plus gentamicin for severe soil contamination. These drugs were continued for 2 to 3 days after the last surgical procedure. The wounds underwent aggressive surgical débridement and irrigation with pulse lavage. The fractures were stabilized with a variety of methods including external fixation, plaster, internal fixation, traction, intramedullary nailing, and external fixation with limited internal fixation. Closure depended on the attending surgeon’s appraisal of the wound after débridement and bony fixation. Six wound management techniques were used. (1) Immediate primary closures were loosely approximated at both the traumatic and surgical extension portions of the wound. (2) Second-look primary closures underwent primary closure with a planned reexploration, débridement, and closure 48 to 72 hours after the initial closure. (3) Delayed primary closures were packed open initially and then approximated loosely after a subsequent débridement. (4) Delayed skin grafts and (5) delayed flaps were used in patients whose wounds were initially managed open. The last category (6) was primary amputation. Eighty-seven fractures underwent primary closure, with 11 returning for a second-look procedure and subsequent closure. Thirty-one fractures were managed by delayed closure, with skin grafts needed in three and flap coverage in eight. One of the 119 cases had a primary below-knee amputation. Primary closure was used in 88% of grade I, 86% of grade II, 75% of grade IIIA, 33% of grade IIIB, and no grade IIIC fractures. The aggressive approach resulted in an overall 7% infection rate (8/118) and 16% delayed/nonunion rate (19/118). Statistical analysis revealed no significant difference in delayed/nonunion and infection rates between immediate and delayed closures. The authors concluded that immediate primary closure (with or without a second look) “is a viable option when carried out by an experienced fracture surgeon.”

Some authors advocate early, if not immediate, flap coverage. The microsurgical reconstruction techniques promoted by Godin revolutionized the concept of free tissue transfer for trauma. Free flaps transformed an open fracture acutely into a well-vascularized closed fracture. Godin evaluated 532 patients undergoing microsurgical reconstruction at three different intervals after injury. Group I (early) received the free flap within 72 hours of the injury, group II (late) between 72 hours and 3 months, and group III (delayed) between 3 months and 12 years. Infection occurred in 1.5% of group I, 17.5% of group II, and 6% of group III. Time to bone healing was 7 months, 12 months, and 29 months, respectively. Flap failure rate was 0.75% for group I, 12% for group II, and 10% for group III. Of the 134 early flaps, 63 were performed in the first 24 hours. The results led the author to conclude that coverage within the first 72 hours after injury provided superior results, with earlier bone healing and decreased rates of infection. In addition, the average length of hospital stay was notably diminished for the early-flap (27 days) versus the delayed-flap (256 days) coverage. Delaying definitive reconstruction resulted in extensive fibrosis, which complicated the microvascular anastomoses and in many instances led to an additional loss of soft tissue and bone.

In a more recent series of early-flap coverage, Gopal et al. reported the results of their “fix and flap” approach for grade IIIB and IIIC injuries of the tibia. Over an 8-year period, 84 fractures were treated with immediate meticulous wound débridement with lavage, skeletal stabilization, and definitive soft-tissue coverage with a vascularized muscle flap and split-thickness skin graft. The goal was to obtain coverage within 72 hours of the injury. Sixty-three fractures were treated with early (<72 hours) flap coverage. Twenty-one patients underwent late (>72 hours) soft-tissue coverage. The deep infection rate was 6% for patients with early flaps and 30% for those with late flaps. Flap failure rate was 3.5%. The authors suggested that delay in coverage is not necessary if healthy soft tissue can be imported reliably into the zone of injury.
Despite studies supporting early closure, the major argument against primary wound closure is its association with the occurrence of gas gangrene. Brown and Kinman documented 27 patients between 1963 and 1973 with clostridial wound infections treated with a variety of antibiotic regimens. Thirteen patients were involved in contaminated water-related accidents. Two patients involved in motor vehicle crashes had apparent fecal contamination secondary to rectal lacerations. The wounds were severely contaminated but were all closed primarily, some in the emergency department. In many cases, “foreign material such as dirt or vegetable matter” was noted throughout the tissues at the time of wound breakdown, indicating incomplete débridement. Only five patients received initial coverage for anaerobic organisms, and four received no antibiotics at all. The authors stated that “antibiotics in various combinations and dosages were changed from day to day without any apparent pattern or rationale.” Although these 19 cases of gas gangrene and 8 of anaerobic cellulitis were attributed to the timing of closure, perhaps the more logical common denominator was the inadequacy of débridement and inappropriate selection for early wound closure treatment.

Surgical Judgment as a Factor in Wound Closure

Although the term is not easy to define, “adequate débridement remains a difficult technical problem.” All nonviable tissue must be removed while as much functional tissue as possible is spared. Likewise, proper tissue-closure tension and optimal wound-closure technique are difficult to define but can be summarized as the methods that are not anticipated to cause additional tissue necrosis. When the possibility of progressive tissue necrosis is uncertain, the wound can be closed initially and subsequently opened, if necessary, for a second exploration.

Surgical judgment, typically gained with experience, is required to successfully use an immediate wound-closure protocol. Obvious exceptions to immediate closure include wounds containing gross contamination with feces, dirt, or stagnant water, as well as farm-related injuries or freshwater boating accidents. Other contraindications are a delay in the initiation of antibiotics beyond 12 hours postinjury or questionable tissue viability at the time of the initial surgery. If a doubt exists concerning the adequacy of the débridement, or in a patient with confounding comorbidities, the wound should not be closed regardless of fracture type or antibiotic coverage.

Summary

Advances in initial wound débridement and irrigation, access to broad-spectrum antibiotic coverage, and experience with modern fracture stabilization techniques enable a more aggressive approach to be taken to open fracture wound care. Considering the many improvements in all aspects of open fracture wound care, the increasing incidence of resistant nosocomial infections, and the cost implications of a dogmatic delayed-closure strategy, wound care protocols for open fractures should be reevaluated. A large, multicenter, randomized, prospective study is required. A pilot study under the auspices of the Orthopaedic Trauma Association is underway. Until better data are available, the best clinical practice may be the adoption of a treatment plan that allows for the earliest possible soft-tissue coverage over a clean, stable, viable zone of injury. If these parameters are achieved at the time of initial débridement, primary wound closure appears to be a reasonable treatment option.

References