Primary *versus* Delayed Soft Tissue Coverage
for Severe Open Tibial Fractures

A Comparison of Results

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Thirty-six Types III and IIIa open fractures of the tibial shaft are presented with a treatment protocol based on early, aggressive wound management and fracture coverage utilizing muscle, myocutaneous, or free flap techniques. There were five amputations, seven deep infections, three nonunions, and no cases of chronic osteomyelitis in the series. The criteria for inclusion in the series were definitive wound coverage by 30 days after injury and end-result records including time of union. Wound coverage was classified as early (0-7 days) or late (8-30 days). Major and minor wound healing disturbances were found in 20.8% of the early and 83.3% of the late groups, with mean union times of 4.0 months and 6.4 months, respectively. Extensive and serial debridements, coverage within five to seven days, and early bone grafting produce a viable soft tissue envelope and a favorable mesenchymal milieu for the healing of complex open fractures. This significantly improves end results with respect to union, tissue loss from infection, healing time, and cost of hospitalization and rehabilitation.

Comparing methods for treating complex open tibial fractures is difficult since the data bases vary among series. Regardless of the treatment offered, the severity of injury remains the most important prognostic indicator of infection and fracture healing. When high-energy forces cause displacement and comminution of bone, severity and devitalization are synonymous whether the fracture is closed or open. The authors have previously reported their protocol to enhance and hasten open fracture wound healing by creating and maintaining a live wound with free or local muscle flaps in open fractures with resultant exposed bone and/or fracture site. The stimulus for this approach began with the conceptualization of the open fracture wound as the interrelated healing processes of the soft and hard tissues, including bone, periosteum, muscle, fascia, and skin. A low infection rate, early discharge from the hospital, and rapid, permanent rehabilitation of the patient have been reported by others utilizing similar techniques. Experience in recent years has confirmed the wisdom of treating Type III open fracture wounds by stable external fixation and modern antimicrobial agents. Still time honored, proved and essential in treating all of these injuries are thorough debridement and protected revascularization of the wound. The present paper reports a combined series of 36 Types III and IIIa injuries to the tibia utilizing primary, delayed primary, or secondary closure tech-
niques, with follow-up periods greater than five months in all cases and with particular reference to union and wound complications. A comparative review of the literature is provided.

MATERIALS AND METHODS

A modification of Gustilo's classification of open fracture wounds\textsuperscript{10,26} was used in the present study because it segregates wounds according to a progressive loss of vascularity/increasing severity. Only Types III and IIIa wounds are reported. The fracture wounds are classified as follows: Type I—low-energy forces causing a spiral or oblique fracture pattern, with skin laceration of less than 2 cm and a relatively clean wound; Type II—moderate-energy forces causing a comminuted or displaced fracture pattern, with skin laceration of more than 2 cm and moderate adjacent skin and muscle contusion but without devitalized soft tissues; Type III—high-energy forces causing a significantly displaced fracture pattern with severe comminution, segmental fracture, or bone defect, with extensive associated skin loss and devitalized muscle; and Type IIIa—fracture pattern as in Type III but with extreme-energy forces, e.g., high-velocity gunshot or shotgun wounds, a history of crush or degloving, or associated vascular injury requiring repair. Farm injuries of Type III are included in this group secondary to the degree of contamination.

Initial emergency room care consisted of tetanus prophylaxis, wound culture, Betadine scrub, saline lavage, occlusive dressing, reduction and immediate splint stabilization, and cephalosporin antibiotic therapy. Patients underwent operation as soon as possible. The first debridement proceeded from the surface to the depths of the wound. The skin was excised according to its pattern of fluorescence or until dermal bleeding was encountered. Any exposed subcutaneous tissue and fascia (stripped of paratenon) were removed. Surrounding muscle was excised if there was any question of its viability based on color, turgor, bleeding, and contractibility. Relatively clean, major bone fragments contributing to fracture stability were retained and, if necessary, transfixed with one or two interfragmentary cortical screws. Small fragments stripped of soft tissue and any grossly contaminated bone were discarded. Following the first debridement, the extremity was brought to length, reduced, and stabilized while the wound was jet lavaged with 6 l of saline, which decompresses marginally vascularized tissues and alters the apparent versus real need for further debridement. The initial stabilization usually was achieved by two half pins placed above and below the fracture in the sagittal plane. Gloves and gowns were changed. A second, more detailed debridement was then undertaken and the wound jet lavaged with another 4–6 l of saline.

There is no need for tentative debridement or concern about exposed bone or vital structures. The surgeon can and must be aggressive in initial and subsequent debridements, secure in the knowledge that coverage ultimately can be obtained with soft tissue flap procedures.

When contiguous compartments have not been decompressed by the trauma and/or the debridement procedure, compartment pressures are monitored by a needle manometer; a formal fasciotomy is performed when pressures are greater than 40 mm Hg. Follow-up readings are performed at six-hour intervals in patients with pressures from 30 to 40 mg Hg until a definite trend can be documented. Four-compartment fasciotomy is performed routinely when arterial repair is required.

Whenever possible, percutaneous, biplanar half-pin stabilization of the fracture is performed utilizing either the Hoffmann or Roger Anderson device with pins based anteriorly (sagittal plane) and medially (coronal plane) on the subcutaneous borders of the tibia. Laterally based pins or "through-and-through" pins have been associated with a high pin tract infection rate except in the proximal, epiphyseal region, where the anterior two-thirds of the tibia is subcutaneous. Quadrilateral interlocking frames are provided. Currently, the sagittal plane alone is utilized if the coverage approach is not apparent or may be compromised by early second-plane fixation. In these instances the second plane is added after flap coverage. Four to five pins are placed above and below the fracture site (two planes combined). With major substance loss or instability of the tibia, the fibula is reduced and maintained by a small intramedullary pin at the time of the final debridement.

Detached but viable muscles are draped over the fracture and exposed bone. If devascularization of the muscles is minimal, formal myoplasty is undertaken to effect primary wound coverage. When the injury is more extensive, the wound and any exposed bone are covered with Betadine-soaked gauze dressings to avoid desiccation. A "second-look" operation under anesthesia is performed 48–72 hours after injury to assess wound viability. Antibiotic coverage is maintained or adjusted to cover organisms isolated from the emergency room cultures. All flaps are released, allowing thorough inspection of the wound bed, and cultures are obtained from the depths of the wound. The fracture site is dislocated to allow inspection of deep compartments; this is easily ac-
Definitive wound coverage is accomplished during the first five to seven days after injury. The preferred modalities are (1) local muscle transfers; (2) local myocutaneous flaps; or (3) distant microvascular flaps. The coverage protocol follows the prerequisites, recommendations, and techniques of various authors. The techniques have changed little since the original descriptions, and these works are essential reading for anyone treating these injuries.

The "workhorses" of the lower leg are the soleus (proximally based) and the medial and lateral heads of the gastrocnemius as myocutaneous or muscle flaps. The proximal three-quarters of the tibia can be covered by combinations of the gastrocnemius, soleus, flexor digitorum longus, anterior tibialis, and extensor digitorum communis muscles. The distal one-quarter is more reliably covered by a free flap. In general, a distally based flap is not recommended for the distal tibia in the severely traumatized extremity; the anastomotic vascular network within these muscles may require as long as three weeks for re-establishment. Crossed-leg coverage must rely on local tissue circulation to support the transfer once the flap has been disconnected from the contralateral extremity; the flap does not bring its own blood supply to the wound, unlike transfers in the other procedures discussed. The dorsalis pedis flap is rarely used because of associated vessel injuries.

If the orthopedic surgeon chooses not to provide the wound coverage, a plastic surgeon should be consulted at the "second-look" operation or, more desirably, at the conclusion of the first debridement to facilitate scheduling and enhance preoperative planning.

Skin grafts are applied primarily or secondarily to exposed muscle and wound bed. After operation, the extremity is elevated 15-20 cm above the pelvis, with no restrictions on trunk positioning. Antibiotic therapy is discontinued five to seven days after wound coverage. The external fixation device is removed when soft tissue healing is complete and/or unstable fractures are amenable to plaster techniques and weight-bearing. The extremity is fitted with a Jobst stocking when the plaster is removed; patients are encouraged to wear the stocking for at least six months after plaster removal.

Bone grafting is performed for unstable fractures two to four weeks after coverage and is usually cancellous, posterolateral, and designed to provide tibiofibular osteosynthesis. Placement of a bone graft beneath the flap may complicate subsequent closure of the wound even if enough "slack" is left in the flap at the original procedure (anticipating the need for grafting), as the muscle shrinks and becomes less pliable in four weeks (Fig. 1). Closed rod fixation and grafting techniques as described by Chapman are of great value in selected cases in which the flap enters and covers the medullary canal. Hansen recommended grafting at the time of flap coverage, but the authors consider this addition of devitalized tissue to a contaminated wound too hazardous for anyone without considerable experience in early coverage techniques.

Exchange of the external for internal fixation systems should be delayed. Widenfalk et al. reported three cases of infected rod stabilization of externally fixed Type III injuries in their series. Whether this represents occult osteitis or contamination from pin tracts is unknown. In such cases the authors recommend that the fixator be removed and the extremity kept to length with either plaster or calcaneal pins-in-plaster. Culture specimens should be obtained from all pin tracts and the patient treated by the appropriate antibiotics for two to three weeks; antibiotic therapy should continue through the perioperative period, being discontinued seven to ten days after operation. A ring sequestrum or gross pin tract infection is a contraindication for internal fixation. The timing for alternative fixation is the same as for the bone grafting procedure.

RESULTS

Results of the present series are tabulated in Tables 1 and 2. Fracture coverage is defined as early if completed zero to seven days and late if completed seven to 30 days after injury. There were 27 Type III and nine Type IIIa injuries in 35 patients, for a total of 36 fractures studied to union. The mean healing times for the early and late coverage groups were 4.0 and 6.4 months, and wound complications (major and minor combined) occurred in 20.8% and 83.3%, respectively. A minor coverage failure associated with su-
FIGS. 1A–1E. (A) Type IIIa wound resulting from a shotgun blast to the anterior compartment and tibia at the conclusion of the first debridement. (B) Lateral gastrocnemius myocutaneous flap at 72-hour second-look procedure. Third-look procedure disclosed minor flap loss and minimal wound bed devitalization. (C) Bone graft at 6 weeks beneath flap. Muscle previously transposed into the fracture defect was then excised to accommodate graft. Only the superior limb of the flap margin was used to preserve peripheral skin anastomoses to the cutaneous portion of the transfer. (D) Fracture healed and patient left unprotected at 4 months. Note ring sequestrum in the diaphysis. (E) Extremity at four months.

Superficial infection was interpreted as one minor complication; a major coverage failure associated with deep infection was considered one major complication. All major coverage failures and amputations were associated with deep infections. Fracture healing was considered complete in the presence of clinical and radiographic evidence of union; nonunion was considered a major complication. Any inflammation, cellulitis, or drainage indicating infection; pin tract infections were not included. Continuity of the inflammatory process with bone was considered a deep (major) infection. Major coverage failures included loss of flap or need for revision, while minor failures included hematoma formation, skin graft loss requiring revision, or minor flap loss requiring only local wound care.

Of the nine Type IIIa injuries, four were early and five were late coverage procedures. Two patients who had early coverage presented with major complications. One of these patients had sustained a close-range shotgun blast to the tibia with major devitalization found at the time of the "second

<table>
<thead>
<tr>
<th>TABLE 1. Results of Flap Coverage in Types III/IIIa Injuries</th>
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<tbody>
<tr>
<td><strong>No. of fractures</strong></td>
</tr>
<tr>
<td>Coverage failure</td>
</tr>
<tr>
<td>Minor</td>
</tr>
<tr>
<td>Major</td>
</tr>
<tr>
<td>Infections</td>
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<tr>
<td>Superficial</td>
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<tr>
<td>Deep</td>
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<tr>
<td>Amputations</td>
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<tr>
<td>Nonunion</td>
</tr>
<tr>
<td>Chronic osteomyelitis</td>
</tr>
<tr>
<td>Union (mean)</td>
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<td>Hospitalization (mean)</td>
</tr>
</tbody>
</table>
### TABLE 2. Type III Injuries—Comparable Series

<table>
<thead>
<tr>
<th>Author</th>
<th>No. of Type III</th>
<th>Percent Deep Infection</th>
<th>Time to Union (mos)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edge and Denham⁶</td>
<td>11/38</td>
<td>30</td>
<td>6 mos (avg)</td>
<td>One late amputation; union times for all 38</td>
</tr>
<tr>
<td>Chacha⁴¹</td>
<td>10</td>
<td>80</td>
<td>13.6 mos (avg)</td>
<td>6.8 mos to soft tissue healing</td>
</tr>
<tr>
<td>Clancey and Hansen¹³</td>
<td>11</td>
<td>55</td>
<td>44% delayed union</td>
<td>2 late amputations; includes internal and external fixation; delayed union defined as no callus at 4 mos</td>
</tr>
<tr>
<td>Karlström and Olerud²⁶</td>
<td>32</td>
<td>0</td>
<td>7.8 mos (mean)</td>
<td>2 late IM rod infections on exchange procedure; 62% healed by 8 mos</td>
</tr>
<tr>
<td>Krempen et al.³⁸</td>
<td>10</td>
<td>0</td>
<td>9.5 mos</td>
<td>12% delayed union</td>
</tr>
<tr>
<td>Mendes et al.⁴⁹</td>
<td>71</td>
<td>4.2</td>
<td>7.6 mos</td>
<td>Union times not noted; 5 flaps transferred</td>
</tr>
<tr>
<td>Gustilo and Anderson²⁶</td>
<td>67</td>
<td>9.9</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Lawyer and Lubbers⁴⁰</td>
<td>10</td>
<td>0</td>
<td>8.8 mos</td>
<td>3 amputations</td>
</tr>
<tr>
<td>Present series</td>
<td>36</td>
<td>19.4*</td>
<td>4.3 mos (mean)</td>
<td>5 amputations in Type IIIa injuries; 0% chronic osteomyelitis; 1 persistent nonunion (1/31)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.4**</td>
<td></td>
<td></td>
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</tbody>
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* Amputations included.  
** Amputations excluded.

look” and coverage; no subsequent debridements were performed, and the limb was eventually amputated. The second of these patients had a Type IIIa injury resulting in nonunion (Fig. 2). In all Type IIIa injuries devitalized tissue has been noted at the “second-look” procedures. As experience with these injuries increased, coverage was performed during the “second look” and the flap lifted for a “third look” within 48 hours; minor flap disturbances could then be noted and resolved at the same time. Of the six major infections in the late group, five were Type IIIa injuries with an average time to coverage of 21 days. Four of the six required amputation; one of these wounds was debrided every 48–72 hours, with devitalized tissue found on all four serial debridements prior to ablation. Two of the seven deep infections were salvaged by redebridement and later bone grafting, for a salvage rate of 28.6%.

There were three nonunions in the entire group, all in Type IIIa injuries. In two successful bone grafting was performed, with union times of nine and 18 months. The latter was a nine-year-old girl with an infected nonunion that healed after serial debridements, plate stabilization, and bone grafting. The third patient refused further surgery and ambulates effectively using a plastic ankle-foot orthosis (Fig. 2).

In 13 other patients (11 Type III and 2 Type IIIa injuries) follow-up evaluation has been inadequate to allow assessment of union (range, 3 weeks–3 months). There were 12 early and one late coverage procedures; the one late coverage was performed at ten days, following a local skin flap failure. There have been no deep infections, major complications, or amputations in this second series; the minor complication rate is 25% (all early coverages) and the average follow-up period is seven weeks.
DISCUSSION

Rhinelander,\textsuperscript{52,53} Gothman,\textsuperscript{24} and Whiteside and Lesker\textsuperscript{64} clearly showed that bone and the surrounding soft tissue share numerous vascular microanastomoses. The proliferation of vessels supplying the muscles and the periosteum accommodates the fracture callus response and revascularizes bony fragments.\textsuperscript{31,54} Holden\textsuperscript{31} identified a lag phase in the healing of fractures with an ischemic soft tissue envelope; the initiation of callus proliferation is delayed until soft tissue vascularity at the fracture site has been restored.

Clinical correlation to these works is found in studies classifying fractures by their relative loss of vascularity (severity): displacement, comminution, fracture pattern, and degree of soft tissue injury (Table 3). Nicoll,\textsuperscript{50} Macnab and De Haas,\textsuperscript{42} Sladek and Kopta,\textsuperscript{57} Lawyer and Lubbers,\textsuperscript{40} Edwards,\textsuperscript{17} Ellis,\textsuperscript{18} and Tonnesen\textsuperscript{59} demonstrated a direct correlation between the energy absorbed by the soft and hard tissues and the complications of wound healing (delayed union, nonunion, infection, skin slough). Wounds that were severe (6–10 cm) but not associated with marked displacement or comminution behaved as Type I or closed injuries; closed wounds with severe fracture patterns were similar to open Type III injuries with respect to union.\textsuperscript{50,59} The mean union time for the combined coverage groups in the present series was 4.3 months (Table 2), consistent with Type I behavior, emphasizing the importance of the vascularity of the tissues involved to the success of wound and fracture healing. The natural history of a well defined injury has been altered by manipulation of wound-healing parameters.

Table 2 lists series that had acceptable classification criteria, external fixation as the treatment of choice, commitment to obtain “coverage” of bone, and use of internal de-

Figs. 2A–2E. (A) Type IIIa degloving injury incurred when a bus backed over the extremity. (B) Reduction and single-plane fixation following first serial debridement and lavage. (C) Soleus and flexor digitorum longus myoplasty coverage performed 8 hours after injury. Note the extensive skin debridement required once the devitalization pattern is identified by fluorescein. (D) Soft tissue healing complete by 4 weeks. (E) Patient refused further surgery for established nonunion at 9 months.
FIGS. 3A–3D. (A) Wound resulting from close-range gunshot wound to the tibia. (B) Initial stabilization and debridement with unfortunate partial fibulectomy for compartment syndrome. (C) Debridement, two-plane fixation with half pins, and soleus myoplasty were performed 28 (late) days after injury following slough of pretibial tissues. (D) Large fragments with some soft tissue attachment that required debridement prior to definitive coverage.

A large fibular Rush pin was used to add stability to the extremity secondary to tibial fracture extension and comminution to the ankle. Bone grafting was performed after 6 weeks of continuous antibiotic therapy.

TABLE 3. Time to Union According to Severity of the Injury

<table>
<thead>
<tr>
<th></th>
<th>Nicoll\textsuperscript{30}</th>
<th>Sladek and Kopta\textsuperscript{37}</th>
<th>Macnab and De Haas\textsuperscript{41}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NW, ND, NC</td>
<td>NW, ND, NC</td>
<td>NW, ND, NC</td>
</tr>
<tr>
<td></td>
<td>91%</td>
<td>91%</td>
<td>60%</td>
</tr>
<tr>
<td></td>
<td>SW, SD, SC</td>
<td>SW, SD, SC</td>
<td>SD</td>
</tr>
<tr>
<td></td>
<td>United by 5 mos</td>
<td>Median healing time</td>
<td>United by 6 mos</td>
</tr>
</tbody>
</table>

N = nil or slight; S = severe; W = wound; D = displacement; C = comminution.
not of Type III or IIIa severity. Types III and IIIa open fractures of the tibia have devitalized, bare bone in the wound that does not support a skin graft unless granulation tissue is encouraged to "incorporate" the bony fragments—a time-consuming process, not without complications. The average time to union tabulated from Table 2 is 8.5 months (other series).

Soft tissue coverage for exposed bone, nonunion, infection, or unstable scar is not a new concept. Ger, one of the pioneers in the field, recently advocated early (14–30 days after injury) coverage of the open fracture with myoplasty after years of experience covering infected, chronic ulcers in conservatively managed extremities. Ger divided his patients into Groups I (coverage 9–30 days after injury), II (coverage after 5 months), and III ("chronic" osteomyelitis). Fifteen wounds were covered within 14 days and seven within 14–30 days after injury in Group I. Minor wound-healing disturbances occurred in three of the seven patients who had late coverage, but there were no nonunions, chronic infections, or major wound disturbances in the 22 patients. Kojima et al. reported a 50% complication rate (partial loss of flaps) in six patients in whom coverage was noted at 30 days (average). Lentz et al. presented eight Type III tibiae with 25% minor and 37% major wound failures. Only three of seven patients were followed up to union, with an average healing time of six months.

The authors have divided Ger's Group I into an early (0–7 days) and a late (7–30 days) group. At The University of Texas Medical Branch, Ger Groups II and III wounds are excised, covered, and reconstructed; the incidence of minor complications is 20%–30% and that of major wound complications 10%. Patients require two to three months of hospitalization, several procedures, and a prolonged rehabilitation phase (8–12 months). The late coverage group is considered to be "infected" at the time of surgery (cellulitis, inflammation, or drainage). Prior to coverage all necrotic tissue, exposed bone, and foreign bodies are removed; the "second-look" concept is upheld. If desiccated bone is left in the wound at the time of late coverage, it sequestrates and causes local wound disturbances. The techniques of debridement are different for early and late wounds; extensive bony debridement is necessary in the latter. All devitalized bone should be removed to bleeding or previously unexposed surfaces, and the medullary canal should be opened in saucer fashion to accept the flap and obliterate dead space (Fig. 3). The authors believe that the difference between these late coverage wounds and Ger's Groups II and III wounds is margination of the wound itself. In the poorly defined wound bed (7–30 days) infection may be low grade and demarcation between involved and uninvolved tissues indistinct, granulation tissue may obscure extension, and the subsequent excision of tissues may be incomplete. Peri-vascular edema and inflammation may be found well outside the primary wound zone. Wounds in the intermediate group (late) may, therefore, undergo inadequate debridement on the basis of the biology of the wound.

The overall deep infection rate in the present series was 19.4%. Five patients required below-knee amputations. Two, with infected nonunions, were salvaged by redebridement and grafting (union at 9 and 18 months). Excluding the five amputations, the deep infection rate is 6.4% (2 of 31). When Olerud and Karlström reported their five-year experience in treating open tibia fractures with the AO osteosynthesis, the impressive 100% incidence of union and lack of infection was associated with hospitalization periods of three months in 20% of the patients and of greater than five months in 10%. The mean time in the hospital for the patients in the present series was 4.2 weeks for the early and 9.0 weeks for the late group (6 weeks of continuous antibiotic therapy). The average time to soft tissue healing in Chacha's secondary...
intention wounds was 6.8 months,11 while Hicks30 reported a 40% incidence of subsequent breakdown in similar wounds in a ten-year period.

The techniques used by trauma surgeons to minimize wound-healing disturbances are varied and often overlooked due to concern with the hard tissues and fixation techniques. Widenfalk et al.65 stated: “It was always the aim that bone be covered by soft tissue. . . If necessary, the fracture zone was covered by myoplasty.”35,36 Since they used the classification system of Rittmann et al.,55 the high percentage of patients not requiring wound reconstruction suggests Gustilo Type II injuries; 36% of their patients underwent either skin grafting on granulation tissue or myoplasties to obtain epithelial coverage. Hansen27 recommended primary myoplasty with the flexor digitorum longus, in Krempe's Case 3 primary myoplasty was performed,38 and Lawyer and Lubbers40 used the anterior muscle groups to obtain coverage “when possible.” Gustilo and Anderson26 utilized pedicle flaps in five patients, all of whom went on to union without infection: “skin grafting was successful over exposed bone when the periostium was intact; otherwise, we resorted to some type of flap coverage.” Only recently has the total wound concept been addressed.

REFERENCES


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