# The Management of Soft Tissue and Bone Loss in Type IIIB and IIIC Pediatric Open Tibia Fractures

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**Purpose:** Type III B and C open tibia fractures in children pose a challenge to the orthopaedic surgeon. Limb salvage is the initial goal for the majority of patients, but managing soft-tissue defects and bone loss can be a challenge. The purpose of this study was to evaluate the use of circular external fixation in the management of these injuries.

**Methods:** In this retrospective review, we examined children with type IIIB and IIIC open tibial fractures treated with circular external fixation and soft-tissue coverage between 1990 and 2010. Chart review included: mechanism and severity of injury, degree of bone and soft-tissue loss, technique and duration of external fixation, additional procedures, clinical and radiographic outcomes, and complications.

**Results:** Eight patients were identified whose average age at the time of injury was 10.4 years (range, 3.8 to 15.3 y). There were 7 type IIIB and 1 type IIIC fractures. All patients received free or rotational soft-tissue flaps. Average bone loss was 5.4 cm (range, 0 to 12 cm). Three techniques of circular external fixation were used, including: (1) static stabilization to allow for soft-tissue coverage and fracture healing, (2) acute shortening with plan for later limb lengthening, and (3) stabilization of the extremity for soft-tissue coverage and intended bone transport. Seven of 8 limbs were salvaged. Of those 7, all were followed to skeletal maturity and ambulating without assistive devices at final follow-up. Three patients had a clinically relevant leg-length discrepancy ($\geq 2$ cm). Four of 8 patients required secondary or contralateral procedures.

**Conclusions:** Pediatric type IIIB and IIIC tibia fractures are limb-threatening injuries that require dynamic thinking and management as the bone and soft-tissue injuries evolve. We have proposed a general algorithm to guide the treatment of these severe injuries. In our experience, circular external fixation, in conjunction with this algorithm, provides the appropriate stability and environment for managing soft tissue and bone loss and can facilitate limb salvage.

**Level of Evidence:** Level IV.

**Key Words:** open fracture, tibia, pediatric, bone loss, external fixation, circular, soft-tissue flap

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Severe open tibial fractures in children are difficult to treat. Challenges can include significant soft-tissue defects, bone loss, physeal injury, neurovascular damage, and concomitant injuries. The long-term management of these fractures can involve treating delayed union, nonunion, infection, as well as subsequent leg-length discrepancy, bone deformity, and joint stiffness.

Approximately 10% of pediatric tibial fractures are open.[1] Only 7% to 10% of these open fractures are type IIIB, with IIIC injuries being even less common (2.6%).[2,3] While there is copious literature on the management of severe open tibial fractures in adults, there is little written in the pediatric orthopaedic literature with respect to treatment guidelines. Publications specifically discussing pediatric traumatic bone loss are especially limited in number. When reported, pediatric segmental defects are rarely quantified. Most studies group children and adults or combine all open tibia fractures together in the analysis. To the best of our knowledge, there is only 1 publication dedicated explicitly to pediatric traumatic bone defects.[4]

In our institution, once a clean wound is obtained through adequate, usually multiple, debridements, pediatric type IIIB and IIIC open tibial fractures are managed with soft-tissue coverage and circular external fixation. The purpose of this study was to review our experience with these injuries with respect to management strategies for soft-tissue defects and bone loss. Our aim was to elucidate a treatment algorithm to assist in the future management of these limb-threatening injuries in children.

## METHODS

After obtaining an IRB approval, a retrospective chart and radiograph review of all skeletally immature patients with type IIIB and IIIC tibial fractures treated with circular external fixation between 1990 and 2010 at a pediatric level I trauma hospital and/or pediatric specialty hospital was performed. Data collected from the chart review included age, sex, date of injury, mechanism of

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trauma, soft-tissue involvement, fracture type, initial management on presentation, amount of bone loss, timing and technique of soft-tissue coverage and frame placement, as well as the duration of circular external fixation. Additional surgical procedures, duration of follow-up, final limb alignment, leg-length discrepancy, and complications were also recorded and analyzed. The small number of patients involved did not allow for statistical analysis of the data.

Fractures were graded using the system of Gustilo and Anderson.[5–7] Fractures with periosteal stripping, contamination, extensive soft-tissue injury, exposed bone, and need for local or free-flap coverage were considered type IIIB. Type IIIC injuries involved fractures associated with vascular injury requiring repair.

## RESULTS

Eight patients met the inclusion criteria and were included in the study. An overview of patients' characteristics and the details of their injury and treatment are presented in Table 1. The average age of the patients at the time of injury was 10.4 years. There were 5 boys and 3 girls.

There were 7 type IIIB injuries and 1 type IIIC fracture. Six of 8 patients had segmental bone loss, averaging 7.2 cm (range, 4 to 12 cm) after debridement of nonviable tissues. The remaining 2 patients without segmental bone loss also had high-energy fracture patterns with a large, devascularized butterfly fragment of 6 cm in one patient and severe comminution in the other. All 8 patients received free and/or rotational flaps performed by the plastic surgery service.

Whether initially managed at an outside facility or at our institution, all patients received intravenous antibiotics and underwent emergent irrigation and debridement with bone segment stabilization through a uniplanar or multiplanar pin-to-bar external fixator. Patients were transitioned from the original external fixator to a circular frame at an average of 24.5 days (range, 3 to 65 d).

Three distinct strategies using the circular external fixator were utilized in the management of the tibial fractures. Patients with minimal bone loss were stabilized with a frame to allow soft-tissue coverage. Patients whose soft tissues would allow had acute shortening to achieve bone-end apposition with a plan to lengthen at a site remote from the fracture (Fig. 1). Finally, patients whose soft tissues would not allow acute shortening to achieve apposition were stabilized with or without minimal shortening (to optimize the soft tissues and fibula) and were treated with bone transport (Fig. 2).

Seven of 8 limbs in our patients were salvaged. One patient had a below-knee amputation 2.5 months after his initial injury when free and rotational soft-tissue transfer failed to achieve adequate soft-tissue coverage. For the 7 patients with salvaged limbs, the average duration of follow-up was 6.0 years (range, 3.1 to 13.0 y), and all 7

**TABLE 1.** Overview Characteristics of Patients With Open Tibial Fractures

| Patients | Age (y) | Mechanism of Injury | Fracture Type | Segmental Bone Loss (cm) | Fixation Strategy | Primary Soft-Tissue Coverage |
|---|---|---|---|---|---|---|
| 1 | 3.8 | MVC | IIIB | 4 | Stabilization + bone transport | Soleus rotation flap |
| 2 | 8.7 | MVC | IIIB | 6 | Stabilization + bone transport | Latissimus free flap |
| 3 | 9.0 | ATV | IIIB | 6 | Acute shortening | Soleus/tibialis anterior rotation flap |
| 4 | 10.3 | PVA | IIIC | 7 | Stabilization + planned transport | Latissimus/serratus free flap (later STSG after necrosis) |
| 5 | 11.4 | ATV | IIIB | 8 | Acute shortening | Gastrocnemius rotation flap |
| 6 | 12.7 | ATV | IIIB | Severe comminution | Stabilization | Gastrocnemius rotation flap |
| 7 | 15.3 | BVA | IIIB | 12 | Stabilization + double-level bone transport | Latissimus free flap |
| 8 | 11.8 | ATV | IIIB | Large butterfly fragment | Stabilization | Latissimus free flap (failed) (subsequent soleus rotation flap) |

ATV indicates all-terrain vehicle; BVA, bicycle versus automobile; MVC, motor vehicle collision; PVA, pedestrian versus automobile.

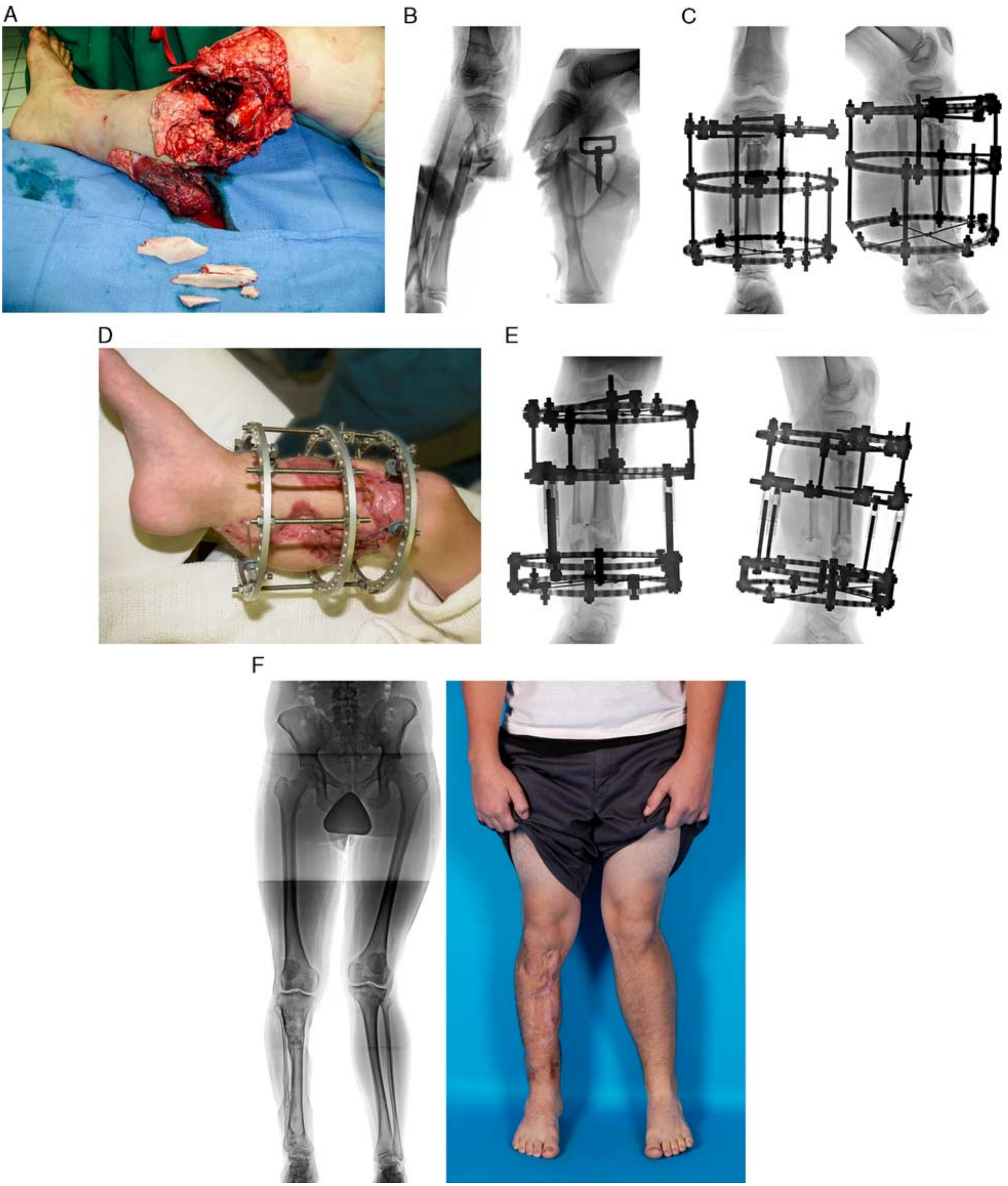


**FIGURE 1.** A, Clinical appearance at time of injury of a 11-year-old male with a severe open tibia from ATV injury (patient #5 in Table 1). B, AP and lateral radiographs at the time of injury. C, AP and lateral radiographs after frame applied with acute shortening showing early evidence toward healing. D, Clinical photograph of the limb when acutely shortened. E, AP and lateral photographs at the completion of initial lengthening. F, Final AP standing radiograph and clinical appearance of contralateral epiphysiodesis.

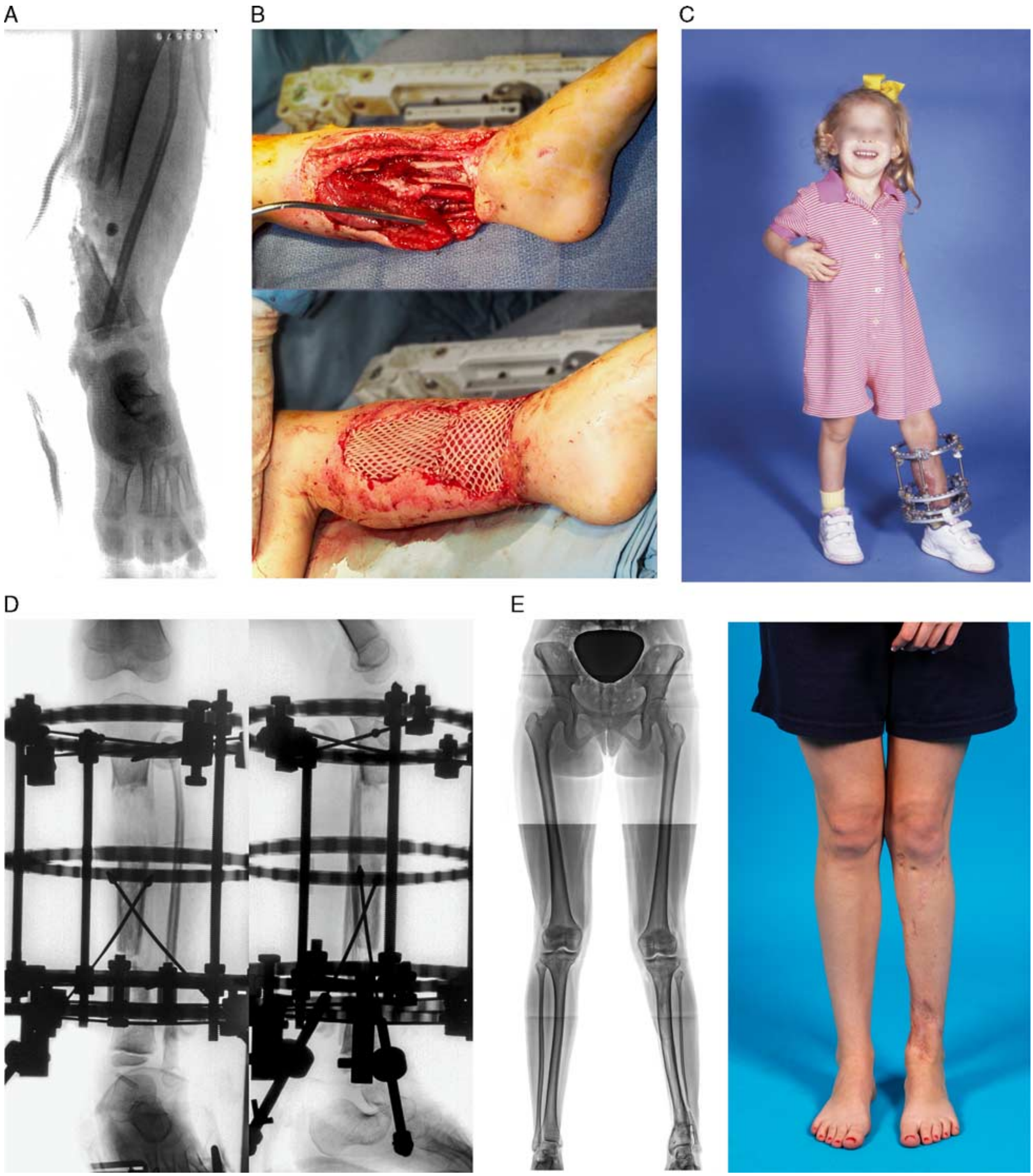

**FIGURE 2.** A, AP radiograph at the time of injury of a 3-year-old female with a severe open tibia with segmental bone loss (patient #1 in Table 1). B, Clinical photograph at the time of soleus flap and skin grafting. C, Clinical photograph with initial frame stabilization to allow bone transport. D, AP and lateral radiographs at conclusion of bone transport. E, Final standing AP radiograph and clinical appearance after multiple procedures for physeal arrest including a secondary lengthening and eventual Achilles tendon lengthening.

were followed to skeletal maturity. The mean duration of treatment in the initial circular external fixator for these 7 patients was 21.6 weeks (range, 11.7 to 36.4 wk).

Patients underwent an average of 6 (range, 3 to 12) significant surgical procedures (not including dressing or cast changes under anesthesia) after initial placement of the circular external fixation frame. Two patients, including the patient who underwent a below-knee amputation, required revision or repeat soft-tissue coverage procedures due to partial or total failure of soft-tissue transfer. Five of 7 patients with limb salvage underwent frame modifications under anesthesia. Four patients underwent autogenous iliac crest bone grafting, including 2 bone transport patients with planned bone grafting at the docking site.

One of the 2 patients with acute shortening subsequently underwent successful limb-lengthening procedures as initially planned. Leg-length discrepancy of the second patient from this group was addressed with a contralateral pan-genu epiphysiodesis. Three of the 4 patients in whom bone transport was planned underwent successful bone transport. One of those 3 patients had bifocal bone transport simultaneously at 2 levels. The fourth patient was initially stabilized in a circular frame, but bone transport was delayed due to significant psychosocial concerns. This patient was temporarily lost to follow-up while in the frame, and upon follow-up, had healed his 7 cm bone defect.

When reviewing additional procedures performed after the bone union was obtained, 4 of 7 patients had a contralateral epiphysiodesis for residual limb-length discrepancy. Two of these 4 patients also underwent placement of a second circular external fixator for gradual angular deformity correction and limb lengthening.

At final follow-up, the 7 patients with salvaged limbs were all ambulating without assistive devices. Four of 7 patients had a foot drop from anterior compartment soft-tissue loss at the initial injury. Three of 7 patients had a clinically significant leg-length discrepancy ($\geq 2$ cm). There was an average final leg-length discrepancy of 1.86 cm (range, 0 to 6 cm).

All 8 patients experienced complications related to the initial injury and/or treatment. Complications included: superficial and/or deep infection, partial or total flap necrosis, delayed union, infected nonunion leading to amputation, ipsilateral growth disturbance due to physeal injury, angular deformity, leg-length discrepancy, ipsilateral fracture proximal to the frame, neurogenic pain, equinus contracture, premature consolidation of distraction regenerate, inability to proceed with treatment plan due to psychosocial concerns, progressive contralateral deformity due to incomplete epiphysiodesis, and foot drop due to initial injury.

## DISCUSSION

Pediatric type IIIB and IIIC open tibial fractures are severe injuries that require aggressive, prolonged, multidisciplinary management. Extensive soft-tissue injury and segmental bone loss can pose significant challenges. On the basis of our experience, we propose an algorithm for the management of segmental bone loss in these limb-threatening injuries using circular external fixation (Fig. 3).

For all fractures associated with segmental bone loss, we recommend acute limb shortening until bone segment

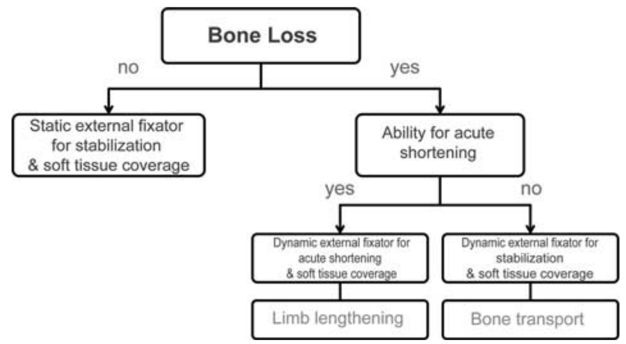


**FIGURE 3.** Proposed algorithm for the management of severe open tibia fractures with segmental bone loss.

apposition is achieved followed by simultaneous or sequential limb lengthening. Although the amount of acute tibial shortening in the adult population is usually limited to $\leq 3$ cm,[8–10] we did not use a strict rule regarding the maximum amount of shortening. In our experience, the condition of the soft tissues and vascular status of the limb dictate how much the extremity can be shortened acutely. Two of our patients tolerated 6 and 8 cm of acute shortening without any neurovascular problems. Acute shortening of the limb minimizes the soft-tissue defect that needs coverage, possibly allowing for rotational flaps or no flap at all.[11,12] We believe minimizing the need for free-flap coverage is preferable, avoiding potential flap complications and donor-site morbidity.

In cases with segmental bone defects when the soft tissues do not allow for acute shortening to the point of bone apposition, the bone segments are then stabilized (with or without some shortening) followed by bone transport. In our personal experience and based on results of other studies,[13] bone transport under flap coverage is well tolerated. Bone transport is a technically more difficult procedure that can be associated with transport segment migration and delayed union or nonunion at the docking site.[9] In cases with more extensive bone loss, bifocal bone transport is also a reliable option for faster elimination of large bone defects.

Not many studies of open tibial fractures discuss segmental bone loss in pediatric patients, and even fewer investigations quantify the bone lost or describe the management guidelines of the bone defect. One recent study specifically addresses pediatric traumatic diaphyseal bone loss, though the population was more heterogenous than in our study, including injury to long bones other than the tibia, bone loss due to infected nonunion, and open fractures types I to IIIB.[4] They reported 5 type IIIB tibia fractures. Similar to our series, they reported a high rate of union (27 of 27), and the duration of treatment was long (average 19 mo until union for the IIIB tibia injuries, 12.3 mo for all injuries).

There is support in the orthopaedic literature for the use of circular fixation in complex pediatric tibia fractures. In a comparison of monolateral and circular external fixation for unstable pediatric tibia fractures, Gordon et al[14] reported that older children (above 12 y) and children with comminuted fracture patterns may benefit from circular fixation over monolateral pin-to-bar frames. Three recent studies have reported good outcomes using hexapod-type external fixation as definitive treatment for complex pediatric tibia fractures, though all 3 series included both closed and open tibia fractures,[15–17] and only 1 mentioned injuries with segmental bone loss.[17]

Soft-tissue coverage within 1 week has been shown to correlate with better outcomes in pediatric patients.[18] There have been reports on primarily adult patients including few pediatric patients, showing benefit of very early (<72 h) or even immediate soft-tissue coverage at the time of fracture stabilization by multidisciplinary team.[19–21] It remains to be seen whether children would also benefit from that earlier coverage. We encourage debridement of all devitalized tissues and devascularized bone, as well as creating a stable environment for adequate and early soft-tissue coverage.

The pediatric literature suggests that severity of injury correlates with time to union and/or complications.[22–30] Our study did have a high number of additional procedures and complications. We believe this is due to the magnitude of the initial bone and soft-tissue injuries and the duration of follow-up. During the extended follow-up in this series, physeal injury was recognized, resulting in angular deformity and limb-length discrepancy which required later treatment.

The major strength of this study is that the patient population treated was unique in the severity of fractures, the amount of bone loss is quantified, and all 7 patients with salvaged limbs have been followed to skeletal maturity. The limitations of the study are the small number of patients and the retrospective nature of the review.

## CONCLUSIONS

Type IIIB and IIIC injuries in the pediatric patient population are uncommon, and each injury is unique regarding the fracture pattern and the extent of soft-tissue injury. We believe that this proposed algorithm of bone defect management using circular external fixation can equip orthopaedic surgeons with a framework for approaching these injuries. The study of the management of type IIIB and IIIC pediatric open tibial fractures would benefit from a larger, multicenter series of patients and from the use of validated outcome assessment tools. Once a child has sustained such an injury, the family should be counseled early-on that treatment is prolonged and often complicated, but that the chances of limb salvage and of return to a functional ambulatory status are high.

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