Ten Year Experience with Use of Ilizarov Bone Transport for Tibial Defects
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Abstract
Tibial defects greater than 4 cm and secondary to high-energy trauma or debridement for infected nonunion pose a significant challenge to the treating orthopaedic surgeon. Twelve patients who had been treated with Ilizarov bone transport for tibial defects over the past ten years were retrospectively reviewed. All patients were male with an average age of thirty-two. Ten of the twelve limbs were categorized as Grade IIIB fractures initially. The average tibial defect at initiation of bone transport was 9.45 cm (range 4 to 20 cm). The mean external fixator time (EFT) was 16.7 months with a mean external fixator index (EFI) of 2.0 months per centimeter. There were a total of 36 complications. Twenty were minor, fourteen were major without sequelae and two were major with sequelae. Overall bone results were good or excellent in nine patients. Overall functional results were good or excellent in eight patients. Ten patients achieved union after Ilizarov bone transport. Use of Ilizarov bone transport can be an effective tool for treating large tibial defects. However, the treatment time is lengthy with a considerable risk of complications.

Large segmental defects of the tibia caused by high-energy trauma or debridement for infected nonunion (Fig. 1) present a significant challenge to the orthopaedic surgeon. These complex problems have historically been treated with bone grafting and vascularized autografting with variable results. More recently, Ilizarov bone transport has been used with good success, as it simultaneously addresses issues of shortening, angular deformity, as well as soft tissue loss and joint contractures.

Previous studies have evaluated this treatment regimen with average defects measuring five to eight centimeters. There have been very few studies evaluating the success and failure of treating larger defects above 10 and approaching 20 centimeters. The purpose of this study was to evaluate the results and complications of Ilizarov bone transport in the treatment of these large tibial bone defects.

Materials and Methods
This study included a consecutive series of the first 12 patients who had completed Ilizarov bone transport for the treatment of large tibial defects from 1990 to 1999 at our institution. All surgeries were performed by the same surgeon. Patient charts as well as all radiographic examinations were reviewed, analyzed, and documented. All 12 patients were male, ranging in age from 20 to 50 (mean: 32 years). Five of the patients had segmental bone loss secondary to high-energy trauma. Seven patients underwent debridement for infected nonunion with a subsequent tibial defect. All 12 patients initially had open fractures with one Grade II, one Grade IIIA, and ten Grade IIIB. Six patients sustained their injury secondary to motorcycle accidents, four were victims of automobile versus pedestrian accidents, and two were victims of gunshot wounds. Six patients were smokers who smoked more than one-half pack per day.

Prior to initiation of bone transport, all 12 patients had a mean of 3.25 previous surgical treatments (range: 1 to 11). When separated into patients who had their defects secondary to segmental bone loss versus debridement for infected nonunion, there was an average of 1.4 procedures (range: 1 to 3) versus 4.6 procedures (range: 2 to 11), respectively, prior to bone transport. The overall average time from injury to Ilizarov bone transport averaged 23.25 months (range: 3
to 100). When separated into segmental bone loss versus debridement for infected nonunion, there was an average of 10.4 months (range: 3 to 39) versus 32.4 months (range: 8 to 100), respectively, prior to bone transport. Eleven limbs had previous external fixators placed, two had open reduction internal fixation, two had previous distraction/compression Ilizarov treatment, four had casts, five had intramedullary nails, thirteen had iliac crest bone grafting and one had ipsilateral vascularized fibular grafting. All treatments were unsuccessful at obtaining union.

At the initiation of bone transport, there was a mean tibial defect of 9.45 cm (range: 4 to 20). All patients were treated by a single-level transport with a five ring apparatus or with a four-ring construct with a pulling wire (Fig. 2). Distraction began approximately seven days after metaphyseal corticotomy and progressed at one millimeter per day. Radiographic evaluation was performed approximately every one to two weeks until docking, then every four weeks during consolidation. If progress to union was not observed three months after docking or if malalignment was evident, the docking site was opened and bone grafted with iliac crest bone graft.

The results were divided into bone and functional results according to the system modified by Paley and Marr. Bone results were based on five criteria: union, infection, deformity, lower limb defect (LLD), and the cross-sectional area of union of the regenerate bone and docking site. An excellent bone result was one that had no evidence of infection,
a deformity of 5° or less in any one plane, an LLD of less than 2.5 centimeters, and a bone union wide enough not to require long-term bracing or protection. A good bone result was union without infection and failure to meet one of the other criteria. A fair bone result was union without infection and failure to meet two of the other criteria. A poor bone result was nonunion and/or persistent or recurrent bone infection.

The functional results were similarly based on five criteria: pain, need for walking aids or braces, deformity or contracture, loss of ankle and/or subtalar motion compared with the preoperative range, and ability to return to normal activities of daily living (ADL) and/or work. An excellent functional result was one in which the patient had no pain or mild pain (not requiring narcotics), did not require a walking aid or brace, did not have joint contracture greater than 5°, did not lose more than 20° of ankle motion, and was able to perform all activities of daily living and/or work. A good functional result was one in which the patient had mild or no pain, was able to perform almost all activities of daily living with minimal difficulty, and failed to meet one of the other criteria. A fair functional result was one in which the patient had mild or no pain, was able to perform most activities of daily living with minimal difficulty, and failed

to meet two of the other criteria. A functional result was considered poor if a patient had significant pain (requiring narcotics), difficulty with activities of daily living, or failed in three of the other criteria.

Statistical analysis did not yield significance in this set of data secondary to the relatively small number of patients in this study.

Results
The mean follow-up time from removal of the apparatus to the time of the last clinic visit averaged 15.3 months (range: 3 to 48 months). The mean (Table 1) external fixator time (EFT) was 16.7 months (range: 9 to 25.5 months). The mean external fixator index (EFI) was 2.0 months per centimeter transported (range: 0.95 to 3.75). Among non-smokers, the average EFI was 1.45 months per centimeter (range: 0.95 to 2.25). Among smokers, the average EFI was 2.60 months per centimeter (range: 1.7 to 3.75).

The total number of operations for the index procedure plus subsequent surgeries for all 12 patients was 27. The mean number of operations per patient was 2.25 (range: 1 to 4 operations). There was a mean of 1.25 additional procedures (range: 0 to 3 operations) per patient during treatment. Two patients required no additional procedures. Six patients required one additional procedure each. Three required two additional procedures each. One required three additional procedures. Additional procedures included revision for drifting transport fragment (two), debridement and grafting at docking site (eight), new ring application (two), repeat osteotomy (one), iliac crest bone graft to regenerate (one), and foot plate addition for equinus contracture (one).

Ten of the twelve patients (83%) had successful unions after Ilizarov bone transport. Two patients had persistent nonunions (17%) after bone transport. Of these two patients, one patient had further treatment after Ilizarov removal (open reduction internal fixation with iliac crest bone grafting) and eventually went on to union. The other patient never achieved union and eventually underwent amputation secondary to a poor clinical outcome. One of the patients who went on to union developed angular deformity and regenerate collapse after Ilizarov removal (Fig. 3).

In total, two of the 12 patients eventually required amputations. One achieved union, however experienced persistent wound drainage and significant joint contractures, which led to a poor functional outcome. The other patient had persistent infection with poor regenerate formation and persistent nonunion.

Five patients (42%) had a residual deformity of greater than 5°. One had progressive varus angulation from 5° to 16° at the regenerate site after Ilizarov removal. Another progressed from 5° to 25° of valgus at the nonunion site. Three others had deformities of 20° of recurvatum (two patients) and 22° of procurvatum at the nonunion site. Three patients (25%) had joint contractures greater than 5° or lost greater than 20° of motion. One had a 10° equinus contracture, the second had both a 15° equinus contracture and 15° knee flexion contracture, and the third had a 20° equinus contracture and 10° knee flexion contracture.

The bone results were graded as excellent in six patients, good in three, fair in zero, and poor in three patients. Of the patients who achieved good bone results, two of the three had residual deformities greater than 5° (25° valgus and 22° of procurvatum, respectively). The other had poor cross-sectional area of union at the docking site and required further protection. Of the patients who achieved poor bone results, one developed significant angulation at the regenerate requiring spatial frame placement as well as persistent wound drainage. Another developed chronic osteomyelitis with significant angular deformity. This patient eventually underwent amputation. The final patient had a persistent infected nonunion with poor regenerate consolidation and collapse and, similarly, eventually underwent amputation.

The functional results were graded as excellent in six patients, good in two, fair in two, and poor in two patients. Of the patients who achieved good functional results, one had a knee flexion contracture greater than 5°, and the other had low-cross sectional area at the docking site requiring long-term bracing. Of the patients who achieved fair func-

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tional results, both had joint contractures greater than $5^\circ$ and loss of joint motion greater than $20^\circ$. Of the patients who achieved poor functional results, both underwent amputation for joint contractures, loss of motion, persistent drainage, or persistent infected nonunion.

Complications were grouped as minor (nonoperative, did not affect final result), major without sequelae (operative, did not affect final result), and major with residual sequelae (affected final result) as per Paley.\textsuperscript{12,14} The total number of complications in this study was 36 with an average of 3.0 complications per patient. There were 20 minor complications (1.66 per patient), 14 major complications without sequelae (1.16 per patient), and two major complications with sequelae (0.16 per patient). Minor complications (Fig. 4) included pin tract infections (nine), docking malalignment (three), major frame change (two), deep abscess secondary to pin (one), wound breakdown at docking site (three), ICBG donor site infection (one), and transient knee flexion contracture requiring serial casting (one). Major complications without sequelae (Fig. 5) included delayed union of the docking site requiring ICBG (eight), deformation through regenerate bone (one), equinus contracture requiring extension of the frame to foot (one), equinus contracture requiring tendo-Achilles lengthening (one), arterial injury secondary to corticotomy (one), complete frame change (one), and delayed consolidation of regenerate requiring ICBG (one). Major complications with sequelae included amputation secondary to persistent infected nonunion and poor regenerate (one) and amputation secondary to persistent infection and significant joint contractures (one).

Discussion

Ilizarov bone transport has been shown to be an effective method for treating tibial defects. Some investigators have compared transport with various bone grafting techniques and have made recommendations to proceed with bone transport for smaller defects of less than six centimeters (larger if a double-level transport is done) and bone grafting for larger defects.\textsuperscript{\textcopyright 5} The vast majority of the literature on this subject addresses patients with smaller defects ranging from four to seven centimeters, all with similar results.\textsuperscript{8-11} Only a few studies have been published addressing larger tibial defects averaging closer to ten centimeters, with some individual cases approaching 20 centimeters.\textsuperscript{12,13} Most notably, Paley and Marr\textsuperscript{12} reported on 19 patients with a mean bone defect of ten centimeters. Segmental tibial bone defect treatment has been fraught with complications as a result of the complexity of the bone and associated soft tissue problems that are present at the onset of the treatment. Bone transport has been reserved as a salvage procedure and thus results are less predictable, as noted in the literature.\textsuperscript{5,9,11,12,14}

Paley and Marr\textsuperscript{12} reported a mean EFT of 16 months with a total of 29 complications for the 19 patients. A mean of

![Figure 3](image-url) Regenerate collapse with subsequent angular deformity.
A, Moderate angulation of transport fragment at docking site and at regenerate interface with fair regenerate formation. B, Further regenerate collapse after removal of Ilizarov apparatus.

![Figure 4](image-url) Incidence of minor complications encountered during treatment with Ilizarov bone transport. By far, the most common minor complication was pin tract infection.

![Figure 5](image-url) Incidence of major complications without sequelae encountered during treatment with Ilizarov bone transport. The most common major complication was delayed union at the docking site requiring iliac crest bone grafting.
2.9 operations per patient was required with ten requiring debridement and/or bone grafting of the docking site at the end of transport. Union was achieved in all cases. Another study from Korea by Song and colleagues reported on 27 cases with an average defect of 8.3 centimeters. They published an average EFT of 8 months and recommended bone grafting at the docking site in order to shorten the duration of treatment and to prevent refracture and nonunion.

This current study reports an average defect of 9.45 centimeters with some defects measuring 15 and 20 centimeters. When compared to similar studies addressing larger tibial defects, the average EFT of 16.7 months is similar. The overall increase in treatment time correlating with tibial defect size appears to be proportionate when comparing studies with smaller tibial defects. Treatment time is a major issue and all available means to decrease EFT to achieve union should be attempted. Although not statistically significant, the trend showing the large difference in EFI between smokers (2.60) and non-smokers (1.45) is a serious issue. Full effort must be made prior to initiating transport to help the patient stop smoking. Both patients who eventually went on to amputation, both patients who developed regenerate collapse and/or angulation, and all three of the patients with lengthier treatment times (EFT greater than 3 months per centimeter), were smokers who smoked more than one-half pack per day.

Once transport is completed and docking has been achieved, several studies now recommend proceeding with bone grafting sooner rather than later (in contradiction to Ilizarov’s initial principles) in order to decrease treatment time. The patients in this study underwent bone grafting at the docking site approximately three months after docking if no healing was evident. By possibly decreasing this lag time, the overall EFT may be shortened. Other studies have recommended double-level transport to help decrease EFT for larger defects. In this study, all patients were treated with single-level transport to simplify treatment and to avoid soft tissue complications, which are more common with double-level transport. In this study, there were very few complications involving soft tissue breakdown, invagination, or severe contracture that did not respond to nonoperative treatment.

However, the number of complications in this study is fairly high compared to previous reports. This is most likely due to the larger mean tibial defect being treated (necessitating longer and more complex treatment) as well as the comprehensive inclusion of all complications in our total tally. The majority of the complications encountered during bone transport can be relatively simply treated either non-operatively or with a fairly straightforward operative procedure. By far, the most common minor complication was pin tract infection. Almost universally (75%), patients develop this complication, which can be effectively treated with enteral or parenteral antibiotics. Some studies do not include pin tract infections in their total tally of complications and, therefore, the number reported in this study is higher. The most common major complication without sequelae was delayed union at the docking site requiring debridement and bone grafting. This occurred in eight of the twelve patients. Similarly, some studies view this not as a complication, but as an expected additional procedure. Once again, the inclusion of this occurrence may increase our apparent rate of complications.

Soft tissue complications including wound breakdown, invagination, and significant joint contractures were not very common in this study as compared to other studies. The patients undergoing bone transport were actively undergoing physical therapy in order to prevent the development of significant contractures. Those that did develop contractures usually had at least partial resolution once the fixator was removed. Furthermore, in order to prevent malalignment and soft tissue interposition, transport was done over a wire placed in the intramedullary canal in four cases. The wire allowed the transport fragment to maintain its proper course and to prevent interposition of soft tissue with subsequent skin invagination.

Patient selection is a critical issue in determining proper candidates for bone transport. The two patients who had the highest number of procedures done prior to the initiation of transport (seven and eleven prior procedures, respectively) were both smokers, and both failed to achieve union with the Ilizarov technique. One of the two patients eventually achieved union with further treatment (although with only a fair functional result), while the other patient eventually underwent amputation. It is, therefore, a reasonable assumption that amputation should be seriously considered rather than transport in smokers who have had numerous attempts at union without success.

Overall, Ilizarov bone transport is an effective salvage tool in obtaining union in patients with an infected nonunion and as a primary tool in patients with large segmental bone loss due to trauma. The lengthy treatment time and considerable number of complications must be fully understood by both the surgeon and the patient prior to undertaking this complex treatment process. In order to obtain union in the most efficient manner possible, the patients should be non-smokers, bone grafting should be done at the docking site if union is not evident after four to six weeks, and transport should proceed over an intramedullary wire placed to guide the fragment as well as to prevent soft tissue interposition and invagination. With these factors at work, as well as close attention to detail, a good or excellent bone and functional result can be expected in the treatment of these large tibial defects.

References

2. Lei H, Yi L: One-stage open cancellous bone grafting of


