Ilizarov Treatment Protocols in the Management of Infected Nonunion of the Tibia

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Objectives: We present a treatment algorithm comprising 4 Ilizarov methods in managing infected tibial nonunion, using nonunion mobility and segmental defect size to govern treatment choice.

Design: Decision protocol analysis study.

Setting: A university-affiliated teaching hospital.

Patients/Participants: Seventy-nine patients were treated with 1 of 4 Ilizarov protocols. All patients had undergone at least one previous operation, 38 had associated limb deformity, and 49 had nonviable nonunions. Twenty-six had a new muscle flap at the time of Ilizarov surgery, and 25 had preexisting flaps reused.

Intervention: Twenty-six cases were treated with monofocal distraction, 19 with monofocal compression, 16 with bifocal compression/distraction, and 18 with bone transport.

Main Outcome Measurements: The primary outcome measure was the absence of recurrent infection. Secondary outcomes included bone union, complications, the Association for the Advancement of Methods of Ilizarov (ASAMI) bone and functional classification scores, and any need for further unplanned surgery.

Results: Infection was eradicated in 76 cases (96.2%) with a mean follow-up duration of 40.8 months (range 6–131). All 3 infection recurrences occurred in the monofocal compression group. Following the initial Ilizarov method alone, union was achieved in 68 cases (86.1%) and was highest among the monofocal distraction (96.2%) and bifocal compression/distraction groups (93.8%). Monofocal compression achieved the lowest union rate (73.7%), significantly lower ASAMI scores, and a refracture rate of 31.6%. Bone transport secured union in 77.8% with a 44.4% unplanned reoperation rate. However, infection-free union was 100% after further treatment.

Conclusions: Monofocal compression is not recommended for treating infected, mobile nonunions. Distraction (monofocal or bifocal) was effective and achieved higher rates of union and infection clearance.

Key Words: infected, nonunion, tibia, Ilizarov, osteomyelitis, segmental bone loss

Level of Evidence: Level III.

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INTRODUCTION

The management of infected nonunion of the tibia is challenging, particularly with segmental bone loss, multiple draining sinuses, poor soft tissue cover, osteopenia, adjacent joint stiffness, limb deformity, or multidrug-resistant polymicrobial infection.[1,2] Permanent functional deficits, prolonged recovery times, and even amputation can result.[3] Despite acceptance of open fracture management guidelines, advances in implant design, and less traumatic surgical techniques, infection is still common after open fracture (9.3%–18%).[4–8] Studies have demonstrated financial costs to be 2 to 3 times higher for infected fractures compared with cases uncomplicated by infection.[9,10]

To eliminate infection, it is critical to resect all necrotic bone and infected segments.[11,12] Ilizarov pioneered the theory of "tension stress" allowing bone and soft tissue generation to restore defects after excision of associated osteomyelitis,[13,14] and in nonunion treatment.[15–21] The Ilizarov method includes several monofocal and bifocal techniques, which permit deformity correction, allow rehabilitation, and secure union of the infected nonunion.[22] However, in many published series, it is difficult to determine how a particular technique was chosen or applied.

We evaluated the outcomes of a treatment algorithm, designed to aid decision making in selecting an appropriate Ilizarov technique in managing a consecutive, prospective series of patients with confirmed infected tibial nonunion. This was based on the degree of stiffness of the nonunion at the time of surgery and the extent of the bone defect after debridement of infection and nonviable tissue.

METHODS

Seventy-nine patients (61 men and 18 women: median age 43.0 years, range 10–84 years) were treated with the Ilizarov method. All patients had infected nonunion, defined as having clinical and radiologic signs of infection in the

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presence of an established nonunion, accompanied by at least one of the following:

- two or more positive sterile site cultures with indistinguishable organisms
- histology supportive of deep active infection
- a draining sinus
- an abscess or intraoperative purulence.

Data Collection

Prospective information was collected on demographics, comorbidities, associated deformity, microbiology and histology data from intraoperative sampling, the nonunion stiffness, complication rate, and outcomes during the treatment period and follow-up.

Nonunion viability was defined according to the classification of Weber and Čech,[23] which classifies the nonunion based on the vascularity of the bone.

Preoperative Evaluation and Planning

All patients were assessed in a multidisciplinary clinic, comprising orthopaedic and plastic surgeons, infectious disease physicians, and a specialist Ilizarov nurse practitioner. Antibiotics were stopped at least 14 days before surgery to aid microbiologic diagnosis.

Surgical Management and Microbiologic Sampling

Surgical excision and tissue sampling were performed according to a previously described protocol.[11,24] If an intramedullary nail was present, it was removed and the canal reamed. The excision was complete when only healthy bleeding bone remained.

After debridement, an assessment of the stability of the nonunion was made. The nonunion was regarded as "stiff" if it had angular bending of less than 7 degrees and axial movement of less than 5 mm on manual testing.[25,26]

Stabilization and Realignment

The choice of the Ilizarov technique used for each case was determined using a simple treatment algorithm (Fig. 1) based on the degree of stiffness of the nonunion, after excision and the size of the segmental bone defect. When deformity was present (38 cases), correction was performed as part of the Ilizarov protocol.

The 4 techniques used in this study were as follows:

1. Monofocal compression: used with mobile nonunions (>7 degrees motion) with segmental bone loss after excision of less than 1 cm (bone touching bone). Acute correction of deformity was done after fibular osteotomy, and the nonunion was compressed. Gradual compression was maintained for 4–5 weeks at 0.5 mm per week.
2. Monofocal distraction: performed in cases with stiff nonunions with no major bone loss. A 4-ring frame was used, and a distal fibular osteotomy was made. Hinges were used to gradually correct angular deformity if present. Distraction was commenced at 1 mm per day for 2 weeks, or until deformity was corrected.

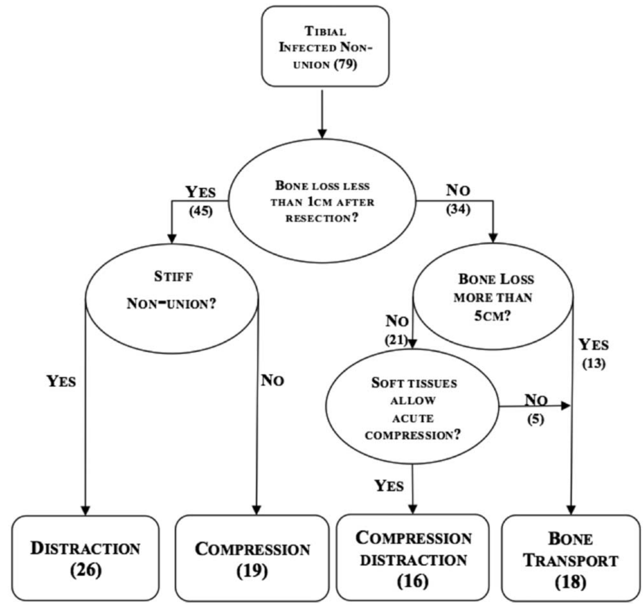

FIGURE 1. Treatment algorithm and numbers treated.

3. Bifocal acute compression and gradual distraction osteogenesis: used with segmental defects of up to 5 cm, when acute shortening could be performed safely without soft tissue or neurovascular compromise. After surgery, the nonunion was compressed at 0.5 mm per week for 4–5 weeks. Leg length equalization was achieved by distraction at the separate metaphyseal corticotomy site, at 1 mm per day after a 1-week latency period (Fig. 2).
4. Bone transport: used with bone defects larger than 5 cm or when the defect could not be acutely compressed without risk to the surrounding soft tissues. Segment transport was commenced after a latent period of 7 days at a rate of 1 mm per day.

In all patients, skin closure was achieved in the same operation, either directly or using local or free microvascular muscle flaps to restore a healthy soft tissue envelope.

Postoperative Care

Vancomycin and meropenem were given intraoperatively, after sampling, and culture-specific antimicrobial therapy was continued for at least 6 weeks. Joint mobilization was commenced on day 2 and early full-weight-bearing encouraged.

Outcome Measures

The primary outcome measure was the absence of recurrent infection. Secondary outcomes included bone union, complications, the Association for the Advancement of Methods of Ilizarov (ASAMI) bone and functional classification scores and any need for further unplanned surgery (defined as any additional surgery undertaken beyond frame removal).

We defined failure of treatment as (1) recurrent infection with positive cultures from further radiologically

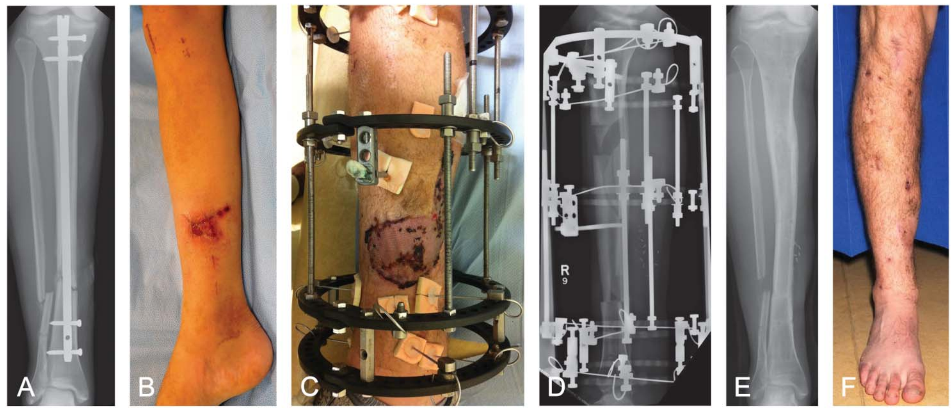

FIGURE 2. Eighteen year-old male with open tibial fracture. Initially treated with intramedullary nail but early wound healing problems. Two months later radiograph shows no sign of progression towards union (A) and large discharging sinus (B). Non-viable bone found during surgery and treated with 4 cm segmental excision, bifocal compression distraction and free gracilis muscle flap, which is seen here at 5 weeks post-op (C). Lateral tibial radiograph at 5 weeks shows completed proximal distraction (D). Total frame time 5.5 months. Radiograph (E) and clinical photograph (F) taken after frame removal, 6.5 months after frame application.

guided aspiration or biopsy; (2) recurrent sinus formation; (3) further surgery performed for infection; or (4) any patient requiring long-term antibiotic treatment for persistent symptoms.

RESULTS

There were a total of 79 cases treated with one of the four different Ilizarov techniques (Fig. 1). Table 1 summarizes the etiology of nonunion and viability. Nonunion was present for a mean of 15.8 months (range 2–168). Patients had a mean of 2.2 previous operations (range 1–5). In the 74 cases with previous fracture stabilization, 28 had plate fixation, 21 intramedullary nailing, 17 monolateral external fixation, 3 Ilizarov fixation, and 8 combined internal and external fixation.

Twenty-five patients presented with muscle flaps in place. These were "reused" where possible. A further 26 cases had a new muscle flap to cover the defect. A free gracilis or latissimus dorsi muscle flap was used in 25 and a local gastrocnemius flap in one (see Fig. 2, which demonstrates a typical case in which microbiologic sampling, metalwork removal, debridement, frame stabilization, and a free muscle flap were undertaken in a single-stage operation).

Patients were followed up for a mean of 40.8 months after frame removal (range 6–131).

TABLE 1. Etiology of Nonunion and Weber and Čech[23] Type

	Nonunion Type						
	Viable			Nonviable			
Etiology	A	B	C	D	E	F	Total
Open fracture	9	5	4	5	9	15	47
Closed fracture	3	6	1	8	3	8	29
Osteotomy			1				1
Failed fibular graft	1						1
Failed ankle replacement						1	1
Total	13	11	6	13	12	24	79

Microbiology

Twenty cases cultured coagulase-negative Staphylococci. Polymicrobial culture was present in 20 cases. Other organisms identified included; 9 methicillin-sensitive *Staph. aureus*, 4 methicillin-resistant *Staph. aureus*, 3 *Pseudomonas* spp., 3 *Enterobacter cloacae*, 2 *Escherichia coli*, 2 *Klebsiella* spp., 2 *Enterococcus faecalis*, 2 diphtheroids, 2 *Streptococcus* spp., 1 *Proteus mirabilis*, and 1 *Morganella morganii.* There were 8 cases with no significant growth but with a positive histology for infection or a sinus present.

Ilizarov Method

Table 2 illustrates the breakdown of treatment techniques against nonunion viability, as defined by the Weber and Čech classification. Monofocal techniques were significantly more likely to be used in viable nonunions ($P < 0.0001$).

In the bifocal techniques, the mean bone defect size was 5.0 cm (see Fig. 2, which demonstrates a typical case). Defects were significantly larger in the bone transport group (mean 6.3 cm, range 3–10 cm) compared with the compression/distraction group [mean 3.5 cm, range 2.5–5 cm (P = 0.00008)].

Acute shortening was not possible in 5 cases with defects under 5 cm because of scarred soft tissues or neurovascular compromise on shortening. When the fibula was intact, with good alignment, bone transport was used to avoid fibula osteotomy.

Infection Recurrence

Infection was eradicated in 76 of 79 cases (96.2%). All 3 recurrences were associated with refracture and followed monofocal compression. Two presented with refracture after union within 8 weeks of frame removal. Both required excision of infected bone and both healed after repeat external fixation and monofocal distraction.

The third case fractured through an area of poor consolidation 6 weeks after frame removal in a grossly swollen limb with stiffness in the hind foot. Biopsy confirmed persisting infection. The patient requested a below-knee amputation.

TABLE 2. Illustrates the 4 Different Ilizarov Protocols Used According to the Weber and Čech[23] Type

	Nonunion Type						
	Viable			Nonviable			
Ilizarov Technique	A	B	C	D	E	F	Total
Compression	2	4	3	3	6	1	19
Distraction	11	7	2	4	2		26
Compression/distraction			1	4	3	8	16
Bone transport				2	1	15	18
Total	13	11	6	13	12	24	79

Union

Mean Ilizarov frame time was 7.5 months (range 3–17). This was significantly greater for bifocal techniques [compression/distraction 9.4 months (range 5–16) and bone transport 10.7 months (range 5–17)] compared with monofocal techniques [compression 6.2 months (range 3–16) and distraction 5.0 months (range 3–11)] ($P < 0.0000001$).

After treatment with all Ilizarov modalities alone, union was achieved in 68 of 79 cases (86.1%). The initial rate of union was: 14/19 (73.7%) for compression, 25/26 (96.2%) for distraction, 15/16 (93.8%) for bifocal compression/distraction, and 14/18 (77.8%) for bone transport. All 4 nonunions in the bone transport group occurred at the docking site. All 11 cases with nonunion were infection-free and healed after further fixation (5 plates, 3 Intramedullary (IM) nails, and 3 external fixators) (Table 3).

Fracture

Eight patients (10.1%) sustained a new fracture at a mean of 10.1 months after frame removal (median 7, range 1–48). Of these 8, 6 occurred in the compression group (representing a 31.6% fracture rate in that group) and 2 occurred in the compression/distraction group (12.5% fracture rate).

Three of the cases in the compression group were associated with reinfection (see the Infection Recurrence section above). Two of these cases were treated successfully with revision debridement and frame fixation, and the other underwent amputation.

All of the 5 remaining aseptic fracture cases were successfully treated with cast bracing (2), intramedullary nail (1), plate fixation (1), or repeat external fixation (1).

Unplanned Surgery

All unplanned surgery undertaken is listed in Table 4. Within the bone transport group, 6/8 cases of unplanned surgery during frame treatment were undertaken to reduce the total frame time by encouraging healing at the docking site.

Wire or pin breakage requiring fixation revision was seen in 4/26 (15.4%) of distraction cases and 1/16 (6.3%) of the compression/distraction cases. Two cases required repeat fibular division to allow lengthening after premature fusion.

Alignment and Leg Length

At the end of treatment, no patient had a significant angular or rotational deformity (>5 degrees). Two patients had a final leg length discrepancy of less than 2 cm and one of 2.5 cm.

Functional Outcome

Table 5 summarizes the ASAMI classification of excellent, good, fair, and poor outcomes for each group.

The compression group had the poorest outcomes, with fewer patients achieving a rating of "excellent" or "good" in the bone and functional classifications (52.6% and 63.2%, respectively). This compares to 96.2% and 100% for the distraction group, 81.3% and 93.8% for the compression/distraction group, and 77.8% and 94.4% for the bone transport group. This difference was statistically significant in both the bone and functional domains ($P = 0.0017$ and 0.00006).

The outcomes for the compression group at final follow-up remained significantly worse than the other treatment modalities, despite secondary surgery, in the functional domain ($P = 0.002$), but not the bone domain ($P = 0.056$).

DISCUSSION

Since 1992, several groups have reported outcomes of Ilizarov techniques in treating infected nonunions of the tibia (Table 6).[18,20,24,27–40] However, the studies are heterogenous, and it is impossible to define why any particular Ilizarov strategy was chosen.

We present the largest series of infected tibial nonunions, treated using an algorithm, designed to help in decision making of Ilizarov strategy.[13,14,19] We have defined indications for each Ilizarov treatment protocol (monofocal distraction, monofocal compression, bifocal compression/distraction, and bone

TABLE 3. Results of the Ilizarov Method Alone and the Final Outcome, by the Treatment Protocol

	Number	Infection-Free (%)	Union Rate Ilizarov Alone (%)	Unplanned Reoperation Rate During Ilizarov (%)	Unplanned Reoperation After Ilizarov Removal (%)	Refracture After Frame Removal (%)	Final Infection-Free Union Rate (%)
Compression	19	16 (84.2)	14 (73.7)	2 (10.5)	7 (36.8)	5 (26.3)	94.7
Distraction	26	100	25 (96.2)	6 (23.1)	3 (11.5)	0	100
Compression/ distraction	16	100	15 (93.8)	3 (18.8)	2 (12.5)	2 (12.5)	100
Bone transport	18	100	14 (77.8)	8 (44.4)	4 (22.2)	0	100
Total	79	76 (96.2)	68 (86.1)	19 (24.1)	16 (20.3)	7 (8.9)	98.7

TABLE 4. Unplanned Surgery Performed During and After Frame Treatment

Unplanned Surgery Required	Compression	Distraction	Compression/ Distraction	Bone Transport	Total
During Ilizarov treatment					
Tethered pin site release			1		1
Bone grafting only	1	2		3	6
Insertion of further pins/wires		4	1		5
Fibular division			1	1	2
BMP only	1			2	3
Freshening of docking site				1	1
Docking site realignment				1	1
After Ilizarov removal					
Tethered pin scar release		1			1
Plating only	1			1	2
Plating and bone grafting	1		1		2
Plating and BMP	1				1
External fixator reapplication	2	1	1	1	5
Intramedullary nail		1		2	3
Below knee amputation	1				1
Total	8	9	5	12	34

transport) based on the biologic and mechanical requirements of each infected nonunion.

The algorithm was easy to apply, being dependent on simple questions that are always possible to answer. It was successful in cases of stiff nonunion and those with larger bone defects after resection of dead bone. The clinical and functional outcome of simple compression was disappointing, considering that these were often viable nonunions with small defects. All recurrences of infection and 71.4% of all refractures during follow-up occurred in this group. This may be due to residual biofilm, containing bacteria, present in the fluid and soft tissue in the "mobile" nonunion gap. The poor outcome implies that the algorithm is not correct in selecting compression as the preferred treatment of mobile, small-defect infected nonunions. We would suggest that these cases may be better treated with larger segmental resection (eradicating infection) and bifocal compression/distraction.

Ilizarov taught that, "infection burns in the flame of regeneration." In our series, infection was eradicated in all 60 of the cases involving distraction, but this may be due to better removal of the infected tissue with a larger resection gap compared with the monofocal compression group. Reliable clearance of infection in the bifocal group offers a significant advantage, allowing safer bone grafting and internal fixation if union is not secured by the Ilizarov method alone.

Monofocal distraction alone produced union in 25/26 cases. This technique allowed accurate correction of deformity, leg length equalization, and bony union within a reasonable fixator time (mean 5.0 months). Our results are comparable to other studies[19,21,31,40] showing high reported union rates in predominantly aseptic, hypertrophic nonunions. We have successfully distracted infected nonunions after excision of only the nonviable bone, providing the nonunion remained stiff after resection.

Bone transport was effective in securing infection-free union in the most difficult cases, with large defects and poor soft tissues. However, we performed a relatively high number of unplanned operations, mainly to secure union of the docking site (6/18; 33.3%). In other studies, bone grafting or freshening of the docking site at the end of transport is commonly reported (50%[20,42] to 80%[43]).

Magadum et al[31] presented 27 cases treated with bifocal compression distraction. They performed acute shortening with no reported complications in defects averaging 10 cm, with the largest defect measuring 17 cm. In our cases, we could not acutely compress such large defects, because

TABLE 5. ASAMI Scores for the 4 Ilizarov Techniques Used

	Asami Scores at the End of Initial Ilizarov Treatment		Asami Scores at Final Follow-up	
	Asami Bone Score (Excellent, Good, Fair, Poor)	Asami Functional Score (Excellent, Good, Fair, Poor)	Asami Bone Score (Excellent, Good, Fair, Poor)	Asami Functional Score (Excellent, Good, Fair, Poor)
Compression	10, 0, 0, 9	8, 4, 4, 2, (1 amputation)	17, 0, 0, 2	8, 5, 4, 1, (1 amputation)
Distraction	23, 2, 0, 1	22, 4, 0, 0	24, 2, 0, 0	22, 4, 0, 0
Compression/Distraction	13, 0, 0, 3	12, 3, 1, 0	16, 0, 0, 0	12, 3, 1, 0
Bone transport	13, 1, 0, 4	13, 4, 1, 0	17, 1, 0, 0	13, 4, 1, 0
Total	59, 3, 0, 17	55, 15, 6, 2, (1 amputation)	74, 3, 0, 2	55, 16, 6, 1, (1 amputation)

TABLE 6. Summary of Published Studies Reporting Results of at Least 10 Cases of Ilizarov Treatment of Infected Tibial Nonunion Since 1992

	Number of Infected Tibial Nonunions	Ilizarov Method Used	Bone Grafting Used	Union	Infection Free	Asami Bone Excellent/Good/Fair/Poor	Asami Function Excellent/Good/Fair/Poor
This study	79	C-19, D-26, C/D-16, BT-18	8/79 had bone graft, 1/79 has freshening of docking site	78/79, 98.7%	76/79, 96.2%	74/3/0/2	55/16/6/1/(1 amputation)
Yin et al, 2015[39]	72, 7 lost to follow-up	BT—65	7/65 had bone graft docking site	65/65, 100%	65/65, 100%	25/27/13/0	46/17/7/2
Khan et al, 2015[38]	24, 1 lost to follow-up	C/D—16, BT—7	No	22/23, 95.7%	22/23, 95.7%	6/14/1/2, (BT 0/5/0/2, CD 6/9/1/0)	8/12/2/0/1 Failure (BT 1/4/1/0/1 Failure, CD 7/8/1/0)
Peng et al, 2015[37]	58	BT—58	100% docking site bone graft & bone marrow injection	58/58, 100%	57/58, 98.3%	30/23/5/0	28/18/12/0
Xu et al, 2014[36]	30	BT—30	3 had debridement of docking site	30/30, 100%	30/30, 100%	28/2/0/0	—
Shahid et al, 2013[35]	20 (8 lost to follow-up)	Not stated	No	12/12, 100%	12/12, 100%	10/2/0/0	6/4/0/2
Wu et al, 2011[34]	25 (3 lost to follow-up)	Stabilisation—22	100% bone grafting	22/22, 100%	22/22, 100%	—	—
Bumbasirević et al, 2010[33]	30	BT—30	1/30	29/30, 96.7%	30/30, 100%	19/10/0/1	13/14/2/1
Madhusudhan et al, 2008[32]	22	C/D—13, BT—9	4/22	22/22, 100%	16/22, 72.7%	4/6/8/4 (C/D 4/3/4/2, BT 0/3/4/2)	1/4/9/4, 4 lost to follow-up (C/D 1/3/6/2, BT 0/1/3/2)
Emara et al, 2008[31]	33	BT—33 (17 with IM nail after frame, 16 with frame only)	100% had bone graft	33/33, 100%	32/33, 97%	32/1/0/0 (with r/o frame then nail 17/0/0/0, frame only 15/1/0/0)	25/3/5/0 (Frame then nail 12/1/3/0, frame only 13/2/2/0)
Magadum et al, 2006[31]	27 (2 lost to follow-up)	C/D—25	No	24/25, 96%	24/25, 96%	19/5/0/1	15/8/1/1
McHale et al, 2004[30]	10	5 BT, 2 C/D, 1 Comp, 2 resection and bone grafting	No	9/10, 90%	8/10, 80%	—	—
Atesalp et al, 2002[24]	14	14 BT	No	13/14, 92.9%	12/14, 85.7%	—	—
Maini et al, 2000[20]	23	12 BT, 4 C/D, 7 monofocal C/D	3/12 BT docking site	23/23, 100%	21/23, 91.3%	15/3/0/5 (BT 5/2/0/5, C/D 3/1/0/0, Monofocal 7/0/0/0)	7/10/0/6 (BT 3/6/0/3, C/D 2/1/0/1, Monofocal 2/3/0/2)
Ring et al, 1999[29]	10	Not stated	3 bone grafting and plate for nonunion	9/10, 90%	6/10, 60%	—	—
Hosny et al, 1998[28]	11	11 C/D	No	11/11, 100%	11/11, 100%	—	5/3/2/1
Dendrinos et al, 1995[27]	28	28 BT	3/28, 10.7%	25/28, 89%	28/28, 100%	14/8/1/5	7/11/4/5 (1 amputation)
Cattaneo et al, 1992[18]	22	22 BT, 6 hemicortical bone transport	No	25/28, 89.3%	23/28, 82.1%	—	—

BT, bone transport; C, compression; C/D, compression/distraction; D, distraction.

of scarred and indurated soft tissues, preventing bony apposition or producing vascular compromise. In cases in which overall limb alignment was satisfactory with an intact fibula, we prefer to retain the intact fibula for stability and undertake bone transport.

We used muscle flaps to provide good soft tissue cover, which is not part of the classical Ilizarov method. Muscle flaps are extremely useful for achieving early soft tissue cover, obliterating the dead space and providing nutrition and antibiotic delivery to the underlying bone.[44–49] They are resilient to distraction and bone transport, but care is required in frame design to allow access for anastomosis and protection of the vascular pedicle during distraction. We always performed the free muscle transfer in the same operation as application of the Ilizarov fixator and started distraction at 7 days after surgery.

In the presence of infection, caution is recommended in the use of both internal fixation and bone grafting.[18] Bose et al reported on 67 long-bone infected nonunions and noted that infection recurrence was significantly higher in the patients treated with internal fixation compared with those managed by external fixation.[2]

Tsang et al[50] treated 32 infected tibial nonunions with exchange nailing but achieved success in only 35%, rising to 61.3% after 2 exchanges. They concluded that the Ilizarov method may be the preferred option in infected cases.

Conway et al[51] reported on their experience of using antibiotic coated nails in treating 43 infected nonunions. A single procedure secured infection-free union in 60%. Infection recurred in 30% of this group. Twelve of the 22 cases with a bone defect (51%) required further surgery to secure union or eradicate recurrent infection. Of note, 12/13 (93%) of the cases requiring further surgery had an associated bone defect. There were no cases of infection recurrence in cases without a bone defect. This may strengthen the argument for Ilizarov techniques when infected nonunion is associated with a bone defect.

Induced membrane techniques as originally described by Masquelet et al[52] have also been used. Morelli et al reviewed 30 years of articles on the induced membrane technique and found only 65 cases reported with individual patient data.[53] Forty-seven percent were for septic bone defects, and union was achieved in 88%, with 93% infection-free, but with a 53% complication rate.

A recent study by Morris et al[54] reporting on 12 patients treated with the induced membrane technique after trauma found that only 5 cases achieved union (42%). A further 5 patients experienced infective complications during treatment, with 2 requiring amputation because of severe infection.

Karger et al[55] reported a series of 84 cases, of which 50% were infected. Although union was obtained in 90%, this was after a mean of 6.11 interventions and a mean of 14.4 months after the first stage reconstruction. Furthermore, the authors advised that weight-bearing was delayed until union had been achieved at a mean of 17.4 months. Average frame times for bifocal compression/distraction and bone transport in our series were 9.4 and 10.7 months, respectively. Our patients are mostly able to weight bear at an early stage, which may prevent other complications, such as muscle wasting and disuse osteopenia.

CONCLUSIONS

Monofocal distraction is the technique of choice in stiff, infected nonunions. Nonviable elements can be excised and distraction can be reliably used to promote union. It offers real advantages for correction of deformity and shortening, with acceptable fixator times. Monofocal compression has a limited place in the management of infected nonunion, and we do not recommend it in nonviable, mobile nonunions.

Bifocal techniques are reserved for those with larger segmental resections and offer a higher chance of eradication of infection and of union but with a significant reoperation rate. This method is now our treatment of choice for infected mobile nonunion of the tibia.

Prolonged treatment in an Ilizarov frame is a major undertaking. Patients may require multiple operations resulting in both psychologic and physical stress. Careful counseling and detailed explanation of the proposed surgery are advocated before beginning this type of surgery. Frequent reassurance is often required, as is careful postoperative surveillance. Any obstacles should be actively managed to avoid complications.

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