Outcomes of Tibial Nonunion in Older Adults Following Treatment Using the Ilizarov Method

Mark R. Brinker, MD† and Daniel P. O'Connor, PhD†*

Objectives: To describe the functional outcomes of treatment using the Ilizarov method for tibial nonunions in older patients (>60 years of age).

Design: Prospective case series.

Setting: Tertiary referral center.

Patients: Twenty-three consecutive patients with an average age of 72 years (61 to 92) who had tibial nonunions for an average duration of 13 months (3 to 46). Fourteen patients had an associated deformity and eight patients had infection.

Intervention: Ilizarov deformity correction, compression, or bone transport.

Main Outcome Measurements: Brief Pain Inventory, American Academy of Orthopaedic Surgeons (AAOS) Lower Limb Core Scale, Short Form (SF)-12, quality-adjusted life years.

Results: Three patients did not complete treatment: two patients died of cardiovascular disease during the treatment period and one patient demanded early removal of the Ilizarov device against medical advice. All 20 patients who completed treatment achieved bony union. Two of the 20 patients died before final follow-up, one patient was unable to participate in follow-up, and one patient was lost. At an average follow-up of 38 months (18 to 61), all of the remaining 16 patients were bearing full weight. AAOS Lower Limb Core Scale scores improved from 39 to 78 points ($P < 0.001$), pain intensity decreased from 3.6 to 0.9 ($P = 0.001$), SF-12 Physical Component Summary scores improved from 26.5 points to 35.3 points ($P = 0.030$), and SF-12 Mental Component Summary scores improved from 41.6 points to 48.7 points ($P = 0.011$). The improvement in quality of life is equivalent to 5.3 quality-adjusted life years per patient, which was larger than the average improvement in quality of life following total hip arthroplasty reported in published series.

Conclusions: Treatment using the Ilizarov method restored function and had a profoundly positive effect on quality of life in these elderly patients with tibial nonunions.

Key Words: elderly, external fixation, deformity, infection

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Nonunion of the tibia in older adults is often complicated by concomitant medical conditions, malnutrition, physical disability, and infection. In some cases, amputation may be recommended in order to end medical treatment and increase survival time.[1,2] Amputation can improve function and quality of life in younger patients who have bone tumors or vascular injuries, but these results do not generalize to older patients. Lower extremity amputation in elderly patients is associated with a high mortality rate, with a 5-year survival rate reported to be as low as 25%.[3–5] Older adults experience a substantial decline in functional status following amputation and are unlikely to return to unaided walking.[3,6,7]

The Ilizarov method provides an alternative for tibial nonunion in older patients. Use of the Ilizarov method has been shown to be effective in the treatment of tibial nonunions and deformities among younger adults.[8–13] To the best of our knowledge, no published series reports the effectiveness and functional outcomes of the Ilizarov method in the treatment of tibial nonunion in adults over 60 years of age. The purpose of this study was to determine the extent to which treatment of tibial nonunion with the Ilizarov method improved function and quality of life in older adults.

PATIENTS AND METHODS

Patients

Patients who were 60 years of age or older at the time that they presented for treatment for a tibial nonunion at our center were included in this investigation. None of the tibial nonunions included in this study were the result of a prior failed ankle fusion. A nonunion was defined as a fracture that had received medical treatment but which, in the opinion of the treating physician, had no probability of healing without further intervention.[14]

The study group was identified from a larger group of 266 patients who underwent surgical treatment after being referred to us with a tibial nonunion between July 1996 and December 2003. Thirty-six of these patients were 60 years or older at the time of treatment. Thirteen of these older patients were excluded from the current investigation for the following reasons. Six patients underwent ankle arthrodesis to treat a distal tibial nonunion involving the articular surface. Seven patients who had not received previous operative treatment underwent internal fixation because their diaphyseal nonunions

From the *Center for Problem Fractures and Limb Restoration, Fondren Orthopedic Group, Texas Orthopedic Hospital; and †Joe W. King Orthopedic Institute, Houston, TX.
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The devices that are the subject of this manuscript are FDA approved.
Reprints: Mark R. Brinker, MD, Fondren Orthopedic Group, 7401 S. Main Street, Houston, TX 77030-4509 (e-mail: mbrinker@houston.rr.com).

had no infection or deformity and had large fragments that were amenable to internal fixation.

The study group was the remaining 23 patients (15 women, 8 men) with an average age of 72.8 years (range, 61 to 92 years; Table 1). The patients had been referred to us an average of 13 months (3 to 46) after their initial injury; no patient received their original fracture care at our center.

The patients had undergone an average of 2.0 (0 to 7) previous surgical procedures. Six patients had had an open tibia fracture as the original injury. These six patients presented to us without detailed medical records regarding their original injury, and therefore the classification of these open fractures was unknown to us. No patient had pending litigation regarding their injury.

The indications for treatment using the Ilizarov method (ie, treatment using an Ilizarov external fixator or a Taylor Spatial Frame) in this series were a tibial nonunion with a viable foot, good plantar sensation, and: 1) an infected nonunion (8 patients); 2) a rigid deformity (6 patients); 3) a periarticular oblique plane deformity (7 patients); or 4) multiple failed previous attempts at internal fixation (2 patients) (Table 2). All older adults with tibial nonunions at our facility undergo preoperative evaluation by an internist and an anesthesiologist to determine if they are candidates for complex reconstruction. For the few patients who are judged inappropriate for complex limb reconstruction for medical reasons, bracing and limb ablation are discussed as treatment options with the patient and family.

The tibial nonunions were located in the proximal third of the tibia in four patients, the middle third in three patients, and the distal third in fifteen patients. One patient had a segmental nonunion, with nonunion sites in the middle third and distal third of the tibial shaft.

All patients had been discharged from clinical care at least 18 months prior to initiation of follow-up for this study. This study was approved by our facility's institutional review board.

Treatment

Seventeen patients were treated with gradual deformity correction followed by compression of the nonunion site (Table 2, Figs. 1 and 2). Three patients were treated with monofocal compression of the nonunion site (Table 2). Two patients were treated with bone transport to bridge a segmental defect (Table 2, Fig. 3). One patient (patient 11) with a segmental nonunion was treated with gradual deformity correction followed by compression of the midshaft nonunion site and compression of the distal nonunion site.

Fifteen patients underwent concomitant autogenous iliac crest bone grafting, and one of these patients also had bone morphogenetic protein-7 (BMP-7) (OP-1, Stryker Biotech, Hopkinton, Massachusetts) applied to the nonunion site (Table 2). One patient (patient 22) had BMP-7 applied to the nonunion site without concomitant autogenous bone grafting.

Infected cases were treated with serial débridements, antibiotic beads, dead space management, and soft tissue reconstruction, as has been previously described (Fig. 3).[14–16]

Patients returned to the clinic every 2 to 4 weeks for monitoring of bony healing. Patients and their families were instructed in pin care cleaning and hygiene. Each pin site was cleaned once or twice daily with a 0.5% chlorhexidine solution. The pin sites were covered with sterile dressings, which were changed after pin cleaning or showering. The pin sites were inspected at each clinical visit, and patients were instructed to call the office immediately if swelling, erythema, purulent drainage, or severe pain was noted at any pin site.

The external fixator was removed when there was radiographic and clinical evidence of bony union. The radio-opaque device sometimes obscures the nonunion site on plain radiographs, making it difficult to assess healing on three of four cortices as recommended by Heckman et al.[17] In such cases, bony union was thus defined as bridging of greater than 25% of the cross-sectional area of the nonunion site as demonstrated on computed tomography (CT) scans.[14] The device was removed in the operating room under general anesthesia in all cases. Postoperative immobilization was not generally required and patients were allowed to bear weight as tolerated.

Patient Evaluation

The most recent follow-up was an average of 38 months (range, 18 to 61) after discharge from care. As part of an ongoing prospective outcomes initiative at our facility, all patients had been enrolled for study at the time of presentation and were re-evaluated at the latest follow-up.

Four standard, validated outcomes questionnaires were used: the American Academy of Orthopaedic Surgeons (AAOS) Lower Limb Core Scale,[18] the Brief Pain Inventory,[19] the Medical Outcomes Survey Short-Form 12 (SF-12),[20] and the Time Trade-Off.[21] Subjects completed these questionnaires using a computerized system in the surgeon's office at their initial visit and at the latest follow-up. At follow-up, subjects were also asked whether they have received any additional treatment related to their tibia since their discharge from our care.

Descriptive statistics were computed for all variables. Independent samples *t*-tests were used to compare descriptive information in various subgroups. Paired samples *t*-tests were used to determine whether improvement had occurred in the outcomes ratings from before treatment to final follow-up. Improvement in quality-adjusted life years (QALY) was computed using the Time Trade Off ratings and the patients' life expectancies.[21] Improvement was computed as the difference between the patients' Time Trade Off ratings at presentation and final follow-up. Life expectancies were estimated from published United States life tables.[22] The product of the Time Trade Off improvement and life expectancy yields the number of QALY. All analyses were performed with SPSS 14.0 (SPSS, Chicago, IL) and Microsoft Excel 2002 (Microsoft, Redmond, WA).

RESULTS

Twenty of the 23 patients completed treatment and achieved bony union with no signs of infection. Two patients died of cardiovascular disease at home during the treatment period, at 3 and 4 months into treatment, respectively. One patient demanded early removal of the external fixator against medical advice and refused any further care. Sixteen of the 20 patients who completed treatment were called in to participate in the final follow-up evaluation that was conducted

TABLE 1. Patient Demographics and History

Patient	Sex	Age (Years)	Original Injury Open	Time From Injury to Presentation (Months)	Prior Operative Procedures*	Comorbidities
1	Male	61	No	3	1. External fixation with limited internal fixation	Type 2 diabetes mellitus
2	Female	63	No	3	1. External fixation	History of smoking (18 pack-years)
3	Female	65	Yes	3	1. External fixation 2. Debridement followed by external fixation	Coronary artery disease, hypertension, smoking (24 pack-years)
4	Female	65	No	11	1. Open reduction, internal fixation 2. Intramedullary nailing 3. Autogenous bone graft 4. Skin graft 5. External fixation	Asthma, anemia, history of acute renal failure, alcohol abuse
5	Male	65	No	3	1. External fixation	Smoking (30 pack-years), cardiac arrhythmia
6	Male	66	Yes	3	1. External fixation 2. Debridement 3. Skin graft	Mitral valve prolapse, history of prostate cancer
7	Female	66	No	46	1. Open reduction, internal fixation 2. Intramedullary nailing 3. Open reduction, internal fixation, bone grafting	Hypothyroidism, anxiety disorder, history of thymectomy
8	Female	66	No	9	1. Open reduction, internal fixation	Hypothyroidism, hypertension
9	Female	67	No	37	1. Open reduction, internal fixation 2. Debridement 3. Debridement 4. Debridement 5. Debridement 6. External fixation, bone grafting, skin graft	Hypertension, anemia
10	Male	67	No	44	1. None (casting)	Smoking (34 pack-years)
11	Male	67	Yes	3	1. External fixation 2. Skin graft 3. Debridement 4. Debridement 5. Debridement 6. Open reduction, internal fixation, skin graft	Type 2 diabetes mellitus
12	Female	70	No	22	1. Open reduction, internal fixation 2. Open reduction, internal fixation 3. Open reduction, internal fixation, bone grafting 4. External fixation 5. Open reduction, internal fixation	Hypertension, anemia
13	Male	70	No	10	1. Open reduction, internal fixation, bone grafting	Type 1 diabetes mellitus, hypertension
14	Male	70	Yes	3	1. Open reduction, internal fixation 2. Debridement	Coronary artery disease
15	Female	74	Yes	5	1. Open reduction, internal fixation	Smoking (42 pack-years)
16	Female	77	Yes	3	1. Debridement 2. Open reduction, internal fixation	Type 2 diabetes mellitus, coronary artery disease, hypertension
17	Male	77	Yes	25	1. External fixation 2. Open reduction, internal fixation	Asthma, history of hepatitis A infection
18	Female	78	No	16	1. Open reduction, internal fixation	Anemia
19	Female	78	No	11	1. Open reduction, internal fixation, bone grafting	Type 2 diabetes mellitus, anemia
20	Female	78	No	13	1. None (casting)	Hypertension, transient ischemic attacks, polymyalgia rheumatica, liver failure
21	Female	80	No	17	1. External fixation	Type 2 diabetes mellitus
22	Female	88	No	12	1. Open reduction, internal fixation	Hypertension, transient ischemic attacks, coagulopathy
23	Female	92	No	5	1. None (casting)	Hypertension, anemia

*Each numbered entry represents a separate trip to the operating room.

TABLE 2. Diagnoses and Treatment Modes for Tibial Nonunion in Older Adults

Patient	Nonunion Type	Infectious Organism at Nonunion Site (From Deep Cultures)	Tibial Region	Indication for Treatment Using the Ilizarov Device	Ilizarov Device Treatment Mode
1	Infected; active, nondraining	*Staphylococcus aureus, Enterobacter cloacae*	Distal	Infected nonunion	Gradual deformity correction followed by compression; autograft
2	Oligotrophic	None	Distal	Periarticular oblique plane deformity	Gradual deformity correction followed by compression
3	Infected; active, draining	*Staphylococcus aureus*	Distal	Infected nonunion	Compression
4	Infected; active, draining	*Staphylococcus aureus*	Distal	Infected nonunion	Bone transport; autograft
5	Oligotrophic	None	Distal	Periarticular oblique plane deformity	Gradual deformity correction followed by compression
6	Hypertrophic	None	Midshaft	Rigid deformity	Gradual deformity correction followed by compression; autograft
7	Oligotrophic	None	Proximal	Multiple failed attempts at internal fixation	Compression
8	Atrophic	None	Distal	Periarticular oblique plane deformity	Gradual deformity correction followed by compression and ankle fusion; autograft
9	Infected; active, draining	*Staphylococcus aureus*	Distal	Rigid deformity	Gradual deformity correction followed by compression; autograft
10	Hypertrophic	None	Distal	Rigid deformity	Gradual deformity correction followed by compression
11	Infected; active draining	*Staphylococcus epidermidis, Candida parapsilosis*	Midshaft and distal (segmental nonunion)	Infected nonunion	Midshaft: Gradual deformity correction followed by compression Distal: Compression; autograft
12	Atrophic	None	Midshaft	Multiple failed attempts at internal fixation	Compression; autograft and BMP-7
13	Infected; active nondraining	*Staphylococcus aureus*	Distal	Infected nonunion	Gradual deformity correction followed by compression; autograft
14	Oligotrophic	None	Proximal	Periarticular oblique plane deformity	Gradual deformity correction followed by compression; autograft
15	Oligotrophic	None	Distal	Periarticular oblique plane deformity	Gradual deformity correction followed by compression; autograft
16	Oligotrophic	None	Distal	Rigid deformity with foreshortening	Gradual deformity correction followed by compression
17	Infected, active draining	*Staphylococcus aureus*	Distal	Infected nonunion	Bone transport with tibial-calcaneal fusion; autograft
18	Oligotrophic	None	Distal	Periarticular oblique plane deformity	Gradual deformity correction followed by compression; autograft
19	Infected	*Staphylococcus hominis subsp. hominis*	Distal	Rigid deformity with foreshortening	Gradual deformity correction followed by compression; autograft
20	Hypertrophic	None	Proximal	Rigid deformity	Gradual deformity correction followed by compression
21	Hypertrophic	None	Distal	Rigid deformity	Gradual deformity correction followed by compression; autograft
22	Hypertrophic	None	Midshaft	Rigid deformity	Gradual deformity correction followed by compression; BMP-7*
23	Oligotrophic	None	Distal	Periarticular oblique plane deformity	Gradual deformity correction followed by compression; autograft

*BMP-7, bone morphogenetic protein-7.

specifically for this study. Two of the 20 patients who completed treatment died before the final follow-up evaluation was performed. One patient was living in a nursing home at the time of final follow-up and was unable to participate in the final follow-up evaluation, according to his family. One patient was lost to follow-up.

All 20 patients who completed treatment returned to full weightbearing. The average time in the external fixator was 283 days (range, 180 to 587). Patients with infected nonunions had a significantly ($t = 3.77$, $P = 0.001$) longer duration in the external fixator (426 days) than did patients without infection (244 days). The two patients (4 and 17) undergoing bone

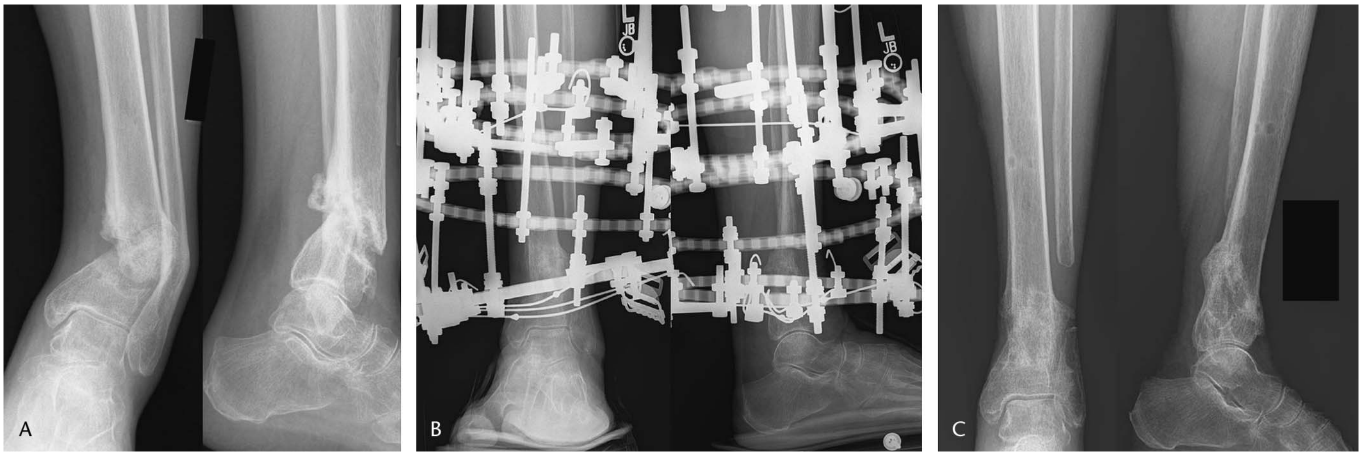

FIGURE 1. A, Presenting anteroposterior and lateral radiographs of an 80-year-old woman (patient 21) with type 2 diabetes mellitus who was referred 17 months following a closed distal tibia fracture treated at an outside facility with external fixation. The radiographs demonstrate a nonunion with an oblique plane angular deformity, which was not reducible using manual traction or reduction maneuvers. B, Radiographs 3 months following application of the Ilizarov external fixator show correction of the deformity and compression being applied (note bending of the wires). C, Final radiographic result at 32 months following application of the Ilizarov external fixator and 23 months following removal of the Ilizarov external fixator (total time in Ilizarov external fixator was 9 months) shows anatomic alignment with solid bony union. Partial fibulectomy was performed to facilitate Ilizarov gradual compression across the tibial nonunion site.

transport had a much longer duration in the external fixator (507 days) than did the patients undergoing gradual deformity correction followed by compression (264 days) or monofocal compression (189 days). Neither age (P = 0.892) nor sex (P = 0.570) had a statistically significant effect on duration of external fixation.

None of the 23 patients developed a deep infection of bone or soft tissues during treatment with the Ilizarov method.

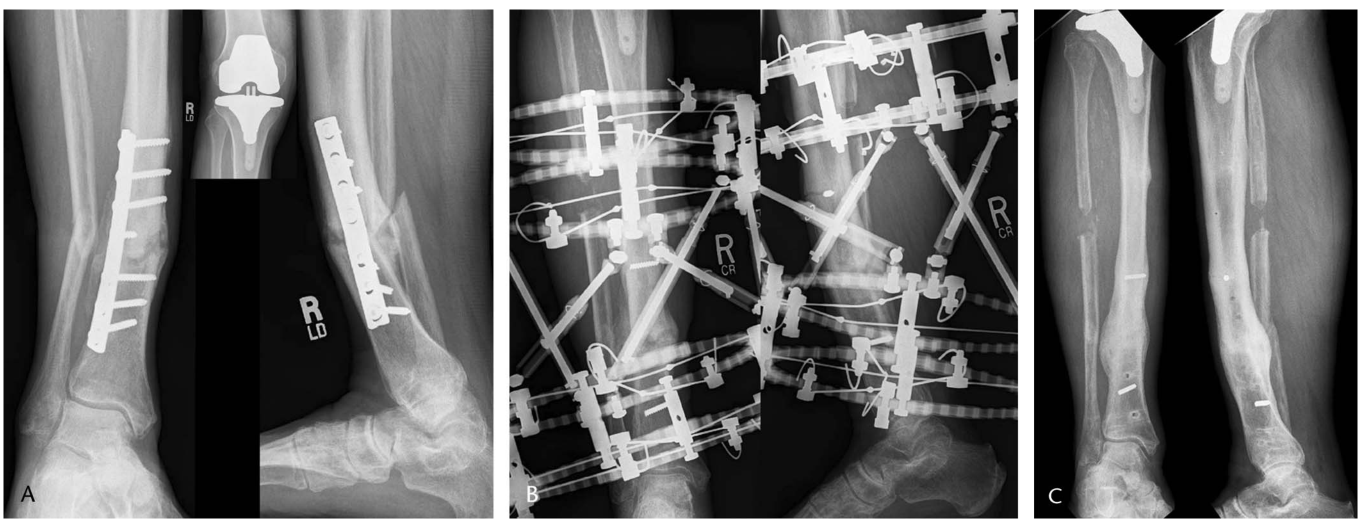

FIGURE 2. A, Presenting anteroposterior and lateral radiographs of a 70-year-old man (patient 13) with type 1 diabetes mellitus and hypertension who was referred at 10 months following a closed distal tibial shaft fracture treated at an outside facility with plate and screw fixation and bone grafting. The radiographs demonstrate a nonunion with deformity. The patient had a recent history of recurrent cellulitis, but no history of purulent drainage from his incision. Preoperative nuclear medicine evaluation was suspicious for infection. Deep cultures at the time of plate removal, local debridement, and bone grafting were positive for *Staphyloccocus aureus*, making this an active, nondraining infection. This case was further complicated by the fact that the patient had a pre-existing ipsilateral total knee arthroplasty. B, Radiographs 2 months following application of the Taylor Spatial Frame show correction of the deformity and compression being applied (note bending of the wires). C, Final radiographic result at 50 months following application of the Ilizarov external fixator and 43 months following removal of the Taylor Spatial Frame (total time in Taylor Spatial Frame was 7 months) shows anatomic alignment with solid bony union and retention of the total knee arthroplasty without clinical evidence of infection.

FIGURE 3. Presenting clinical photograph (A) and anteroposterior and lateral radiographs (B) of a 77-year-old man (patient 17) with asthma who was referred 25 months following an open distal tibia fracture treated at an outside facility with temporary external fixation followed by open reduction with internal fixation. The photographs demonstrate purulent drainage from multiple sites and the radiographs demonstrate the classic findings of an infected nonunion with necrotic bone. Deep cultures at the time of the initial debridement were positive for *Staphyloccocus aureus*. This patient was treated with serial débridements, wide resection of infected bone including the tibia, fibula, and talus, and antibiotic beads. Soft tissue reconstruction included free flap coverage. C, Early radiograph 2 weeks following application of the Ilizarov external fixator shows a large segmental defect. D, Time sequence shots (with number of postoperative days) of a single level bone transport from proximal to distal with progressive maturation of the proximal regenerate and docking of the tibia with the calcaneus. E, Final radiographic result at 54 months following application of the Ilizarov external fixator and 35 months following removal of the Ilizarov external fixator (total time in Ilizarov external fixator was 19 months) shows anatomic alignment with successful tibial-calcaneal fusion.

Six of the 20 patients who completed treatment had seven complications during the treatment period. None of these complications delayed or prevented bony union. Three patients (1, 5, and 13) developed cellulitis that required hospital admission for intravenous antibiotics. Two patients (9 and 18) developed infection (purulent drainage) of a single pin site that was successfully treated by 750 mg ciprofloxacin twice a day for 2 weeks. One of these patients (18) later broke one of the wires on her distal ring. The wire was replaced as an outpatient surgical procedure. No other patient in this series required wire removal or replacement. The last complication was wound breakdown of an anterior incision in one patient who had thin skin (12). The incision had been made by us through a previous surgical site in order to remove failed internal fixation hardware. This patient required a local rotational flap procedure by a plastic surgeon, which healed completely.

The outcomes results described below reflect the functional results for the 16 patients who participated in the final follow-up evaluation. At the time of final follow-up, none of these 16 patients had had any type of tibia or ankle surgery since discharge from our care. All 16 patients continued to ambulate full weightbearing.

Function and quality of life improved for all 16 patients who completed the final follow-up evaluation (Table 3). The AAOS Lower Limb Core Scale scores improved significantly from 39 points (17 to 85) at presentation to 78 points (60 to 96) at the latest follow-up ($t = 4.82$, $P < 0.001$). The average of the Brief Pain Inventory intensity items decreased from 3.6 out of

TABLE 3. Results of Ilizarov Treatment of Tibial Nonunion in Older Adults

Patient	Days in Ilizarov Treatment	Months to Final Follow-Up	Final Average Pain Intensity	Final Subjective Quality-of-Life Rating
1	432	47	0	Excellent
2	272	25	0	Very Good
4	427	19	3	Fair
5	187	Patient living in nursing home and unable to participate in final follow-up		
6	247	55	0	Excellent
7	180	Patient was lost to follow-up		
8	253	46	1	Very Good
9	283	61	4	Good
11	287	19	0	Very Good
12	198	35	4	Very Good
13	217	43	1	Very Good
14	198	45	0	Excellent
15	189	Patient died before completing final follow-up		
17	587	35	3	Good
18	423	52	1	Very Good
19	239	31	1	Good
20	212	30	1	Fair
21	275	23	0	Excellent
22	264	18	0	Good
23	275	Patient died before completing final follow-up		

Patients 3, 10, and 16 did not complete treatment (patient 3 died of cardiovascular disease three months into treatment, patient 10 demanded early removal of the Ilizarov device against medical advice and failed to return for follow-up, and patient 16 died of cardiovascular disease 4 months into treatment).

10 to 0.9 out of 10 (t = 3.71, $P = 0.001$; Table 3). The average of the Brief Pain Inventory interference items decreased from 5.5 out of 10 to 2.2 out of 10 (t = 3.39, $P = 0.002$). Ten of the 16 patients (63%) reported their quality of life as "very good" or "excellent."

The average SF-12 Physical Component Summary (PCS) scores improved from 26.5 points (20 to 46) to 35.3 points (24 to 59; t = 2.03, $P = 0.030$). All 16 patients who completed the final follow-up evaluation had improvements larger than the reported standard error of measurement for the PCS scores (5.3 points), which has been suggested as a meaningful change in score for individuals.[20] The average SF12 Mental Component Summary (MCS) scores improved from 41.6 points (36 to 52) to 48.7 points (37 to 58; t = 2.57, $P = 0.011$). Ten patients had a MCS score change that was larger than the reported standard error of measurement (6.4 points), suggesting that a meaningful change had occurred,[20] and 6 patients had a MCS score change smaller than the standard error of measurement, suggesting that no meaningful change had occurred.

Before Ilizarov treatment, these 16 patients indicated that they would be willing to trade an average of 5.2 years of a theoretical 10 years of remaining lifespan (52%) in exchange for perfect health. At the most recent follow-up, the 16 patients indicated that they would be willing to trade an average of only 1.3 years of the theoretical 10 years (13%) in exchange for perfect health. The product of improvement in Time Trade Off ratings (52% – 13% = 39%) and average expected remaining lifespan (13.6 years) yielded a pretreatment to posttreatment difference equivalent to 5.3 quality-adjusted life years per patient. That is, on average each patient gained the equivalent of an additional 5.3 years of perfect health.

DISCUSSION

In the current series, all of the 20 older patients with tibial nonunion who completed Ilizarov treatment achieved bony union while increasing their function and quality of life. The effect of treatment of tibial nonunion with the Ilizarov method on quality of life was relatively large in these older adults (5.3 QALYs). We calculated the QALYs for total hip arthroplasty and lower extremity amputation for peripheral vascular disease using our cohort of patients with an average remaining lifespan of 13.6 years and the published preference scores[23,24] for these procedures. Our calculations showed that our patients would have 4.9 QALYs following total hip arthroplasty and 2.7 QALYs for amputation for peripheral vascular disease. In as much as hip arthroplasty is considered to result in one of the largest positive effects on quality of life in all areas of medicine, we conclude that treatment of tibial nonunion with the Ilizarov method had a profoundly positive effect on quality of life among our older patients. Our patients also experienced a significant decrease in pain ($P < 0.001$) and increase in function ($P < 0.001$) as a result of Ilizarov treatment, thus improving their overall quality of life relative to their presenting status.

The average patient age in previous reports of treatment of tibial nonunions using the Ilizarov method ranged from 27 years to 42 years.[8–13,25–27] Although several of these studies included a few individuals over 60 years of age,[11,25–27] our patients had an average age of 73 years and a minimum age of 61 years, making

TABLE 4. Reports of Treatments for Tibial Nonunion That Included Patients 60 Years of Age or Older in the Recent Literature

Treatment Method	Author (Date)	Number of Patients in Study (Age Range)	Number of Patients ≥60 Years of Age	Validated Outcomes Measures	For Patients ≥60 Years of Age	
					Rate of Bony Union After Initial Procedure	Final Outcome
Functional bracing	Sarmiento et al (2003)	67 (16 to 67 years)	Not specified	None	Not specified	Not applicable
Fibular transposition	Kassab et al (2003)	11 (16 to 61 years)	1	None	United	Not applicable
High-energy extracorporeal shock wave therapy	Rompe et al (2001)	19 (19 to 65 years)	1	None	United	Not applicable
Intramedullary nailing	Richmond et al (2004)	32 (17 to 71 years)	8	None	88%	Not applicable
	Megas et al (2001)	50 (18 to 72 years)	Not specified	None	Not specified	Not applicable
Exchange nailing	Wu et al (1999)	25 (17 to 65 years)	1	None	United	Not applicable
	Hsaio et al (2006)	54 (21 to 72 years)	Not specified	None	Not specified	Not applicable
Blade plate with autograft	Reed and Mormino (2004)	11 (34 to 67 years)	3	AOFAS Score	100%	AOFAS Score: 93 Points
	Chin et al (2003)	13 (21 to 73 years)	1	None	United	Not applicable
Staged debridement, soft tissue grafting, and bone grafting	Schöttle et al (2005)	6 (37 to 61 years)	1	None	Failed to Unite	Not applicable

AOFAS, American Orthopaedic Foot and Ankle Society Ankle and Hindfoot.

the current investigation a unique study of an older adult population. The rate of bony union in the prior studies of younger populations ranged from 89% to 100%, with excellent or good functional results in 64% to 92% of the patients.[8–13,25–27] The rate of bony union among the 20 patients who completed treatment (ie, those who did not die while in the frame nor insisted on early frame removal) in our study was 100%. All 16 patients (100%) who were able to complete the outcomes instrument at the latest follow-up had improved their functional ability, as indicated by the AAOS Lower Limb Core Scale.

The duration of Ilizarov treatment for patients with tibial nonunions in previous reports ranged from 4.6 months to 13.6 months, with the longer durations associated with segmental defects of the tibia treated by bone transport and infected tibial nonunions.[8–13] Our patients' average duration in the external fixator (9 months) was within this time frame. Our patients with infected nonunions averaged 14 months in the device and those undergoing bone transport averaged 17 months in the device. Thus, our results in older adults were comparable to previously reported results among younger adults with respect to the rate of bony union and duration of treatment. We are conservative with respect to device removal, particularly in the elderly. Premature removal with refracture or bending at a regenerate or nonunion site is a mistake we avoid at all costs; our philosophy in patients with complex problems is that a month or two too long in the frame is greatly preferable to removing it one day too early.

In an effort to identify treatment alternatives for tibial nonunion in older adults other than the Ilizarov method, we searched the recent medical literature. We entered the key words "tibia" and "nonunion" and tibia and "ununited" in a PubMed search limited to the last 10 years and studies of human subjects with subjects 45 years of age and older. The initial search identified 129 articles. Of these, 119 were eliminated for the following reasons: no patients 60 years of age or older; evaluation of fracture or arthritis treatment rather than nonunion treatment; evaluation of articular nonunion treatment (we had no cases of articular nonunion); and evaluation of nonunions due to osteotomy or failed allografts.

The remaining 10 articles reported several alternative treatments for tibial nonunion in older adults (Table 4).[28–37] Very few patients over 60 years of age were included in these investigations. Only one of the studies reported the use of a validated outcomes instrument. Consequently, it is difficult to compare our patients' improvements in functional abilities, health status, and quality of life to these prior studies.

The Ilizarov method has several advantages for older patients with nonunions. Older patients often have concomitant medical problems that may interfere with the treatment of tibial nonunion. First, many older patients have osteopenic or osteoporotic bone.[38] Poor bone quality may not provide adequate purchase for certain types of internal fixation,[14,39–41] but in our experience the tensioned wires and half-pins of the Ilizarov and Taylor Spatial Frame constructs function well in osteopenic bone. Second, older adults may have skin, muscle, or vascular problems, which could lead to difficulties with wound healing, particularly when prominent internal fixation hardware is used. Third, the additional biological stimulation of the Ilizarov method (eg, compression, distraction) may be beneficial to facilitate healing in the older population, among whom bone repair can be delayed for a variety of reasons.[14] Fourth, a particular advantage of the Ilizarov method is the ability for patients to immediately bear weight with tibial nonunion. This is particularly advantageous in the older population where inactivity leads to rapid deconditioning and may also lead to medical complications and problems.

Postoperative care of the patient being treated with Ilizarov external fixation, including pin care, daily hygiene, physical therapy, and pain management, is important for maximizing successful outcomes. This is particularly important in older patients where social issues and cognitive impairment may have a negative effect on outcomes. Preoperative consultation with the patient's family and friends should be sought in order to ensure adequate postoperative care and support.

Amputation as a treatment for tibial nonunion should be reserved for those older patients who have multiple medical problems that preclude lengthy treatment. In some cases, amputation is the most efficient way to solve a chronic medical problem and preserve life.[1,2] Older patients, however, do not recover their health or functional ability to the same extent as do younger patients following amputation.[3–6] The Ilizarov method provides an alternative to amputation that not only preserves the limb, but also increases quality of life, restores functional ability, and improves overall physical health status among older adults with tibial nonunions.

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