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Bone Tumor Reconstruction With the Ilizarov Method

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Background and Objectives: Patients with musculoskeletal tumors can face large bone deficiency, deformity, and nonunion. Distraction osteogenesis via the Ilizarov method may be useful for reconstruction of these deficiencies allowing limb preservation and optimizing function.
Methods: We reviewed 20 patients with a range of musculoskeletal tumors necessitating surgical treatment. The group included 9 females and 11 males with a mean age of 22.6 (8–58) years at a mean follow up of 81.7 (26–131) months. The mean bone deficiency was 7.9 (1.2–18.0) cm.
Results: The mean lengthening achieved was 7.1 (3.5–18.0) cm over an EFI of 33.5 (range, 9.5–58.3) days/cm. This treatment resulted in 10 excellent and 3 good ASAMI bone scores, 10 excellent and 3 good ASAMI function scores, a mean lower extremity MSTS score of 93% and a mean upper extremity MSTS score of 87%. Treatment resulted in 2 complications, 18 obstacles, and 6 problems.
Conclusion: The Ilizarov method is an effective technique for limb reconstruction of bone tumors, although extended time in external fixation is required. Since no one in this group received simultaneous chemotherapy or radiotherapy, we cannot comment on use of the Ilizarov method with these treatments. Further use and clinical follow-up is warranted.
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Key Words: Ilizarov method; limb salvage; limb reconstruction; limb length discrepancy; bone tumor

INTRODUCTION

Malignant and benign bone tumors can lead to bony defects, deformity and limb length discrepancy either primarily or as a result of surgical resection. The orthopedic oncologist is faced with the challenge of both the optimal treatment of the tumor and the subsequent bony reconstruction. Bone defects following tumor resection are often treated with vascularized fibula grafts, prosthesis, and/or allograft reconstruction [1–5]. Distraction osteogenesis offers an additional therapeutic; however, comparatively little is written about this method [5–8].

The purpose of this study is to assess the safety and efficacy of limb reconstruction using distraction osteogenesis and the Ilizarov method to correct limb length discrepancies and deformities arising either directly from bone tumors or secondarily from the treatment of bone tumors. We have used this method to restore function in patients with bony tumors in a wide variety of ways, including: primary reconstruction through lengthening or bone transport following resection of malignant bone tumors; lengthening and/or deformity correction for growth arrest caused by benign bone tumors; secondary reconstruction after failure of other primary reconstruction modalities that resulted in nonunion or deformity. As such we hypothesize that formal review of our experience will show that the Ilizarov method can be used safely in our patient population while yielding good to excellent functional results.

MATERIALS AND METHODS

After receiving approval from the Institutional Review Board we performed a retrospective review of patients from 2002 to 2011 with function limiting deformities and bone loss related to musculoskeletal oncologic conditions and resultant treatment (Tables I and II). Twenty patients were identified. Patient information including demographics, clinical course, location and magnitude of deformity, surgical procedure and time to healing was collected. There were 11 females and 9 males with a mean age of 22.6 years old (range, 8–58) with a mean follow-up of 81.7 months (range, 26–131 months). The primary diagnosis leading to resection included a range of malignant and benign bone lesions. Patients were separated into those with malignant and benign bone tumors for the sake of pathological classification; however, with respect to bony reconstruction, patients were divided into those with bone length deficiency versus those with angular deformities. Length deficiency patients required bone lengthening for LLD and/or bone defects. Patients were classified as angular deformities if they required <2.5 cm of lengthening as defined by the Association for the Study and Application of the Method of Ilizarov (ASAMI) criteria [9]. The ASAMI criteria were used to subdivide the group allowing for more meaningful comparison of the bone deformity following resection which dictated treatment to a greater extent than did the primary diagnosis necessitating resection. Importantly, none of the patients in this study received chemotherapy or radiotherapy, as all were assumed to have undergone curative resections without risk of recurrence. At last follow-up, none of the patients had recurrent disease.

For the limb lengthening patients, External Fixator Index (EFI) in days wearing external fixation per 1 cm of lengthening was used as an objective measurements of time in the frame. EFI does not accurately capture the nature of an angular deformity correction and thus it was not calculated for those in the angular deformity group.

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TABLE I. Patient Demographics

Age	22.6 (range 8–58 years)
Primary diagnosis	Osteosarcoma (n = 3)
	Ewing's sarcoma (n = 1)
	Chondrosarcoma (n = 1)
	Giant cell tumor (n = 1)
	FHMO (n = 1)
	Maffucci syndrome (n = 1)
	Paraosteal osteosarcoma (n = 1)
	Osteofibrous dysplasia (n = 1)
	Osteogenic sarcoma (n = 1)
	Non-Hodgkin's lymphoma (n = 1)
	Unicameral bone cyst (n = 2)
	Fibrous dysplasia (n = 3)
	Ollier's disease (n = 3)
Sex	Female (9)
	Male (11)
Bones involved (some patients had multi-focal disease)	Humerus (4)
	Radius/ulna (3)
	Tibia (9)
	Femur (6)
	Fibula (2)
	Pelvis (1)
Mean duration in fixator (days)	204.1
Mean External Fixator Index (days/cm)	33.9
Mean follow-up (months)	81.7 (26–131) months

All patients were followed in the office with serial X-rays. Final clinical outcomes in all patients were assessed according to the Musculoskeletal Tumor Society (MSTS) score [10]. The MSTS Score uses a 0–5 grading system for each of six subscales: pain, function and emotional acceptance in both upper and lower extremities; plus supports, walking and gait for lower extremities; or, hand position, dexterity and lifting ability for upper extremities. Patients undergoing lower extremity correction (15/20) were also evaluated according to the ASAMI classification [9]. In the ASAMI classification, the bone result is based on four criteria: union, infection, deformity, and leg length discrepancy. An excellent result is defined as union without infection, deformity $<7^\circ$ and a leg length discrepancy <2.5 cm. A good result is defined as union plus any 2 of the last 3 features of excellent. A fair result was union plus any 1 of the 3 features. A poor result is defined as nonunion, refracture or 0 of 3 features of excellent. The ASAMI functional result is based on five criteria: presence of a limp, stiffness of the knee or the ankle, pain, soft-tissue sympathetic dysfunction, and the ability to perform previous activities of daily living (ADL). An excellent result implies a fully active individual; good and fair results indicated progressively lesser degrees of activity/mobility. Delayed union was defined as a healing time of more than 6 months. Bony union was defined by the presence of mature bridging callus across three of four visible cortices on anteroposterior and lateral radiographs and painless full weight bearing.

The Ilizarov method was used for both primary and secondary reconstructions. Primary reconstructions included bone transport after tumor resection as well as lengthening and deformity correction. Secondary reconstruction included nonunion repair, lengthening, deformity correction and bone transport procedures after previous reconstructions with allograft or free fibula transfers.

Adverse events were noted and classified as problems, obstacles, or true complications in the method previously described by Paley [11]. Problems are those postoperative issues that required no operative intervention to resolve (i.e., superficial pin site infections). Obstacles were those issues which required operative intervention, but which then were no longer issues after operative intervention (i.e., contracture release). True complications were those which occurred intra-operatively or those which did not resolve despite operative intervention.

RESULTS

Correction of Limb Length Discrepancy and Bone Defects

The bone lengthening group (deficit >2.5 cm) was composed of 22 surgeries performed on 18 patients. The mean bone deficit in this group was 8.25 (3.5–18.0) cm. The mean time in the frame was 223.9 (range, 76–467) days. The mean external fixation index (EFI) across all length corrections was 33.5 (range, 9.5–58.3) days/cm in the 21 surgeries using external fixation (one surgery used an expandable intramedullary rod). The EFI for bone transport was 39.7 (range, 22.5–58.3) days/cm while that for lengthening was 31.5 (range, 9.5–43.4) days/cm. The mean lengthening achieved was 7.1 (range, 3.5–18.0) cm resulting in a mean residual discrepancy of 0.85 (range, 0–6) cm. Treatment resulted in 10 excellent and 3 good ASAMI bone scores and 10 excellent and 3 good ASAMI function scores.

Correction of Isolated Angular Deformities

There were 10 surgeries performed on 8 patients with the intention to correct angular deformities but not lengthen. The average net multiapical deformity (sum of angular deformity in coronal, sagittal, and axial planes) was 49.6° (range, 25–66). The average time in frame needed for angular correction was 95.6 (range, 28–149) days. Treatment resulted in 3 excellent and 4 good ASAMI bone scores and 5 excellent and 2 good ASAMI function scores.

Aggregation of Cases

Outcomes were evaluated according to modified ASAMI classification for the 15 patients undergoing lower extremity correction. The bone results were 11 excellent and 4 good. The functional results were 11 excellent and 4 good. The MSTS score for the 6 patients undergoing upper extremity corrections was 87% (70–100). The MSTS score for the 15 patients undergoing lower extremity correction was 93% (87–100). (Table II) Adverse events encountered during treatment period were 2 complications (radial nerve palsy with significant but incomplete resolution, premature consolidation), 18 obstacles (recurrent deformity in children, pin site abscess requiring drainage, tarsal tunnel syndrome, and contracture requiring release, docking site nonunion, and regenerate fracture), and 6 problems (contracture treated with physical therapy, pin-site infection; Table III).

DISCUSSION

The purpose of this study was to assess the safety and efficacy of limb reconstruction using distraction osteogenesis and the Ilizarov method following treatment of a range of benign and malignant bony conditions. Based on a review of 20 such cases we believe that this approach yields good to excellent functional results with a minimal rate of serious complication, albeit over the course of protracted external fixation. This conclusion builds on a well-developed literature showing successful use of this reconstruction approach in other settings.

Distraction osteogenesis has been used to effectively treat segmental bone defects in the setting of trauma or nonunions [12–15]. Originally, Ilizarov and others stabilized the limb with a circular external fixator, and the distraction site was produced by an osteotomy of the metaphysis. The original lengthening technique has been

TABLE II. (a) Description of Benign Cases and (b) Description of Malignant Cases

Patient	Age	Diagnosis	Problem list	Treatment	Distraction (mm)	Frame (days)	ExFix Index (days/cm)	Complications	Outcome	Scores
(a) Description of benign cases										
1F	8	Ollier's humerus	Humerus apex anterior 40°	Peds MLF	70	168	24	None	Recurrence of deformity after 6 years	ASAMI: n/a
			Humerus 70 mm short							MSTS: 100
	14		Humerus apex anterior 60°	Peds MLF	67	135	20.15	None	Full ROM	
			67 mm short	Gradual correction					No LLD	
			Recurrence of deformity	Proximal humerus epiphysiodesis					No deformity	
			Growth arrest							
2F	27	Giant cell	Failed nonvascular fibula graft	3 cm ulna transport for ulna-carpal fusion	30	172	57.33	None	Full elbow flex-extend and finger ROM	ASAMI: n/a
		Tumor	Infection						Stable wrist fusion with one bone forearm	MSTS: 73
		Radius	1.5 cm radial defect with cement spacer						No deformity	
			Ulna 4 cm short of carpus							
3M	19	Unicameral bone cyst	11 cm LLD	MLF	90	246	27.33	None	Full ROM	ASAMI: n/a
		Humerus	Poor terminal reach	Gradual lengthening					Minimal deformity	MSTS: 100
4F	14	Ollier's femur	3.9 cm LLD	MLF	30	130	43.3	None	Full ROM	ASAMI-B: E
			Varus femur	Tibia/fibula osteotomy					No LLD	ASAMI-F: E
			Valgus tibia	Gradual lengthening					No deformity	MSTS: 100
5F	13	Unicameral bone cyst	Distal fibular growth arrest	MLF	12	28	23.3	None	Full ROM	ASAMI-B: E
		Fibula	Lateral ankle instability	Fibular osteotomy					No LLD	ASAMI-F: E
			Lateral talar shift	Gradual lengthening					No deformity	MSTS: 97
6F	22	Fibrous dysplasia	1.2 cm LLD	Removal nail	0	149	n/a	None	Full ROM at hip	ASAMI-F: G
			65° femoral neck shaft angle	Proximal + distal osteotomy					No LLD	
		Femur	70° multi-apical deformity	Acute correction with MLF					90° neck shaft angle	
		Fibrous dysplasia	Valgus deformity	CEF	0	80	n/a	None	Knee ROM 0–80°	
		R. Tibia		Distal tibia osteotomy					No deformity	
				Gradual correction					No LLD	
		Fibrous dysplasia	48° Multiapical deformity	CEF	0	122	n/a	None	Knee ROM 0–90°	
		L. Tibia	20° of hyperextention at knee	HTO					Minimal deformity	
				Gradual correction					No LLD	
7F	58	Fibrous dysplasia	12.9 cm LLD	LATN (lengthening):	80	76	9.5	None	1.5″ lift for equines deformity	ASAMI-B: G
			37° tibia valgus	Tibia/fibula osteotomy						ASAMI-F: G
			15° external rotation	Gradual correction						MSTS: 80
		Tibia	Equinus contracture	IM Nail 8 wks later						
			Valgus deformity tibia	Removal LATN nail	0	145	n/a	None	Full ROM	
			Adduction hip contracture	CEF					No deformity	
				Tibial osteotomy					1 cm LLD	
				Gradual deformity correction						
				Adductor tendonotomy						
8M	10	Osteofibrous dysplasia	7 cm LLD	Repair of nonunion	50	157	30.4	Refracture	Partial recurrence of deformity	ASAMI-B: G
			Oblique plane deformity (43° procurvatum, 8° varus, 15° internal rotation)	CEF						ASAMI-F: E
		Tibia/fibula		Gradual deformity correction						MSTS: 97
	12		2 cm LLD	Plate fibula	21	190	n/a	Refracture	Partial recurrence of deformity	
			Tibia 13° valgus	Tibial osteotomy						
			Distal fibula nonunion	Gradual correction						
	13		Bilateral genu valgum	Hemiepiphysiodesis	n/a	n/a	n/a	None	Full ROM	
									1.2 cm LLD	
									Minimal genu valgum	

(*Continued*)

TABLE II. (*Continued*)

Patient	Age	Diagnosis	Problem list	Treatment	Distraction (mm)	Frame (days)	ExFix Index (days/cm)	Complications	Outcome	Scores
9F	26	Maffucci syndrome	9.5 cm LLD	CEF	80	313	39.1	Knee Extension contracture; treated with quadplasty	Symmetrical knee ROM	ASAMI-B: E
			50° procurvatum, 20° varus	Distal femoral lengthening & deformity correction					1 cm LLD	ASAMI-F: E
		Femur	s/p BKA						Functional alignment with prosthesis	MSTS: 97
10F	21	FHMO	1.5 cm LLD	CEF	0	90	n/a	None	Full ROM	ASAMI-B: E
			25 mm lateral MAD	HTO					No LLD	ASAMI-F: E
		Tibia							0 mm MAD	MSTS: 100
		FHMO	4 cm LLD	MLF	45	252	56	Deficient regenerate; treated with: grafting and plating at frame removal	Wrist ROM: extension 45°, flexion 10°, pronation/ supination 50% of unaffected sides	ASAMI: n/a
		Radius		Gradual correction of radius						MSTS: 70
11M	29	Fibrous dysplasia	Old pathologic femur fracture	CEF	35	118	33.7	Ankle equinus; treated with gastroc release	Full ROM	ASAMI-B: E
		Femur	3.5 cm LLD	Tibia/fibula osteotomy					No LLD	ASAMI-F: E
				LATN					No deformity	MSTS: 100
12M	35	Ollier's radius/ulna	25° apex radial forearm deformity	CEF	0	93	n/a	None	Full elbow, wrist and finger ROM	MSTS: 100
				Opening wedge osteotomy					Minimal deformity	
		Ollier's humerus	Bilateral shortening	Bilateral MLFs	75	174	23.2	None		
			Bilateral varus deformity	Gradual lengthening						
(b) Description of malignant cases										
13M	13	Ewing's sarcoma	Nonunion s/p allograft reconstruction	8 cm resection of nonunion	80	467	58.38	Abscess of proximal tibia requiring I&D	Docking site nonunion; successfully treated with locked plate, proximal tibia/fibula synostosis, and DBM graft	ASAMI-B: G
			Procurvatum deformity	Bone transport using bifocal CEF:						ASAMI-F: E
		Tibia	55 mm medial MAD	Distal osteotomy						MSTS: 87
			4 cm LLD	Prox. nonunion compression						
			Proximal tibial arrest (4 cm predicted)	Routine nonunion grafting						
	15		8 cm LLD	ISKD nail	28	n/a	n/a	Premature consolidation	5 cm LLD	
	19		Tibial vara	Bifocal CEF:	0	120	n/a	None	Full ROM	
			72 mm medial MAD	Nonunion compression					6 cm LLD; treated with lift	
			7 cm LLD (2 cm from deformity)	HTO					0 mm MAD	
			Stiff nonunion	Removal ISKD						
14M	43	Lymphoma	Growth arrest of pelvis s/p XRT	MLF	30	159	53.0	Pin site abscess	Full ROM	ASAMI-B: E
			2.5 cm LLD	Femur lengthening					No LLD	ASAMI-F: E
		Pelvis		Quadplasty					No deformity	MSTS: 87
15F	18	Osteosarcoma	Allograft nonunion	Nonunion resection	115	420	36.52	Ankle contracture	Knee ROM 0–120°; Full ankle ROM	ASAMI-B: E
			13° varus	CEF Double level transport				Tarsal tunnel syndrome; treated with release	No LLD	ASAMI-F: E
		Tibia	3 cm LLD	Routine bone grafting					No deformity	MSTS: 93
16M	16	Chondrosarcoma	18 cm mid-diaphyseal defect	CEF Double level transport	160	360	22.5	Docking site malalignment	Docking site nonunion	ASAMI-B: E
				Routine docking site grafting					2.3 cm LLD	ASAMI-F: E
		Tibia	Docking site nonunion	IM nail + plating						MSTS: 100
				Docking site grafting	n/a	n/a	n/a	None	Union Full ROM No deformity 2.3 cm LLD	

(*Continued*)

TABLE II. (*Continued*)

Patient	Age	Diagnosis	Problem list	Treatment	Distraction (mm)	Frame (days)	ExFix Index (days/cm)	Complications	Outcome	Scores
17F	11	Osteosarcoma	21° varus deformity	MLF	70	187	26.7	Free fibula graft fracture; treated with locking plate	Full ROM	ASAMI-B: E
			Free fibular graft nonunion	Repair nonunion					No LLD	ASAMI-F: G
		Femur	Distal femur growth arrest	Deformity correction						
			Knee flexion contracture	Staged distal femur lengthening				Flexion contracture; treated with quadplasty	Minimal deformity	MSTS: 93
			4 cm LLD + 3 cm predicted							
18F	18	Paraosteal osteosarcoma	12 cm bone deficient s/p resection	MLF	117	283	24.2	Extension contracture; treated with quadplasty	Docking site nonunion	ASAMI-B: E
		Femur		Bone transport over nail				Pin site abscess; treated with I&D and exchange nailing.		ASAMI-F: G
			IM nail failure Docking site nonunion	Exchange nailing	n/a	n/a	n/a	None	Knee ROM 0–90° 2 cm LLD Minimal deformity	MSTS: 90
19M	13	Osteogenic sarcoma	s/p humerus resection treated with fibular graft	MLF	90	386	42.9		Regenerate graft fracture	ASAMI: n/a
			Shoulder arthrodesis	Fibular graft osteotomy						MSTS: 80
		Humerus	9 cm LLD from proximal humerus growth arrest	Gradual graft lengthening						
			Fibular graft regenerate fracture	Plate	n/a	n/a	n/a	Radial nerve palsy with 80% resolution.	Return to preoperative ROM	
				Bone grafting					No LLD Minimal deformity	
20M	13	Osteosarcoma	Infected tibial nonunion	Repair of nonunion	0	130	n/a	None	Knee 0–130°	ASAMI-B: E
			30 mm medial MAD	CEF					1 cm LLD; treated with lift	ASAMI-F: E
		Tibia	Procurvatum deformity	Gradual deformity correction					0 mm MAD	MSTS: 100
			2.5 cm LLD following resection + 1 cm projected growth	MLF	37	101	27.9		Knee & Ankle ROM symmetrical	
				Femoral lengthening					No LLD	

ASAMI-B, ASAMI Bone score (E = excellent, G = good); ASAMI-F, ASAMI Function score (E = excellent, G = good); MLF, monolateral frame; CEF, circular external fixator; ISKD, intramedullary skeletal kinetic distractor, Orthofix, Lewisville, TX; LATN, lengthen and then nail; HTO, high tibial osteotomy; MAD, mechanical axis deviation; LLD, limb length discrepancy; ROM, range of motion; FHMO, familial hereditary multiple osteochondromatosis; XRT, external radiation therapy; I&D, incision and drainage.
Minimal deformity: <5 degrees. Partial recurrence: 6–10 degrees.

TABLE III. Adverse Events by Paley [13] Classification

Patient	Event	Management	Paley class
13	Premature consolidation of expanding nail lengthening site	External fixation	Complication
19	Partial radial nerve palsy	Expectant	Complication
8	Recurrent deformity	Hemiepiphysiodesis	Obstacle
1	Recurrent deformity	External fixation	Obstacle
10	Deficient regenerate	Plating and grafting	Obstacle
19	Regenerate fracture	ORIF locked plate	Obstacle
13	Docking site nonunion	Nonunion repair with locked plate	Obstacle
13	Pin site abscess	I&D	Obstacle
9	Knee extension contracture	Quadricepsplasty	Obstacle
16	Docking site nonunion	Nonunion repair with plate + nail	Obstacle
18	IM nail failure	Exchange nailing	Obstacle
18	Knee extension contracture	Quadricepsplasty	Obstacle
18	Pin site abscess	I&D	Obstacle
17	Knee extension contracture	Quadricepsplasty	Obstacle
17	Regenerate fracture	ORIF with locked plate	Obstacle
15	Ankle flexion contracture	Gastrocnemius release	Obstacle
15	Tarsal tunnel syndrome	Tarsal tunnel release	Obstacle
14	Ankle flexion contracture	I&D	Obstacle
11	Ankle flexion contracture	Gastrocnemius release	Obstacle
8	Regenerate fracture	ORIF with locked plate	Obstacle
4	Knee extension contracture	Physical therapy	Problem
7	Pin site infection	Antibiotics	Problem
7	Post-removal cellulitis	Antibiotics	Problem
11	Pin site infection	Antibiotics	Problem
8	Pin site infection	Antibiotics	Problem
8	Knee extension contracture	Physical therapy	Problem

I&D, irrigation and debridement; ORIF, open reduction and internal fixation.

expanded to include bone transport allow for closure of more varied defects, including those arising from oncologic resection (Figs. 1–3). In both classic lengthening and free segment transport the osteotomy site fills with new bone while the fragments are gradually drawn apart during the process of distraction osteogenesis (Figs. 4–6). The docking site heals in compression while the patient ambulates as tolerated (Fig. 7). Subsequent histologic studies have confirmed that the bone regeneration is by way of endochondral ossification [16][17]. Despite corticotomy, healing will occur readily as long as the periosteum is maintained. In the event of difficult union a range of internal fixation can be used to stabilize the bone fragments (Fig. 8). Successful treatment of post-traumatic bone defects with the Ilizarov technique has been reported by many authors [12–15]. However, its application to bone defects seen after resections for musculoskeletal tumors has only rarely been reported [9–13][18]. Additional reports are limited to bone defects only after benign tumors [5][19][20]. Our series emphasizes the feasibility of applying the Ilizarov method to reconstructions of the large bone deficits and multiplanar deformities arising from either benign or malignant tumors with good results (Fig. 9).

Bone tumors often leads to bone defects and/or compromised epiphyseal growth potential in children either primarily or secondarily following surgical resection. This in turn can result in limb deformity, nonunion and LLD. Reconstruction options are limited for patients and are mostly directed towards deformity correction. Closing wedge corrections led to further bone loss and increased limb length discrepancy. Acute, opening wedge corrections require bone grafting with associated risks of nonunion and hardware failure in compromised bone. The Ilizarov method was employed in our patients to achieve deformity correction and/or limb length equalization. Distraction osteogenesis with gradual correction using external fixation achieved both goals successfully and simultaneously.

Fig. 1. Care of Patient 16 (Table II). Preoperative plain radiograph showing tumor.

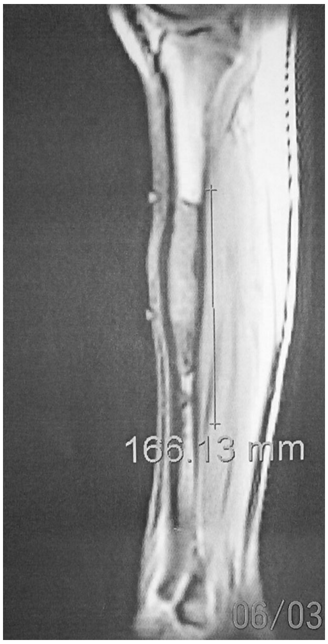

Fig. 2. Care of Patient 16 (Table II). Preoperative MRI scan showing tumor.

In the era of improved chemotherapy, the disease-free survival and overall survival of patients with bone malignancies has improved significantly [21][22]. Current techniques to reconstruct bone defects arising from bone tumors involve complex surgery and carry the associated risks. Allograft reconstruction is limited by the risks of disease transmission and potential failures of the graft to incorporate. As such, it may not be the ideal solution for reconstructions in weight bearing extremities. Vascularized fibula grafting is not without disadvantages. Donor site morbidity, often involving the remaining ‘‘good’’ limb, is a significant concern in these patients. In addition, graft patency and viability after surgery can pose significant obstacles to obtaining good functional status. The use of hypothermic sterilization and subsequent autograft reimplantation has also been reported [3][23]. However, long-term disease-free survival following frozen autograft is difficult to predict because the largest series to date was reported at 30 months and showed approximately 55% of their patients to be disease free, 25% dead and 20% with active disease [23]. Further follow up may be needed before this technique is used more widely. Our results indicate that limb reconstruction surgery using the Ilizarov method is highly successful for bone tumors even under conditions of significant segmental bone defects after resection for malignancy.

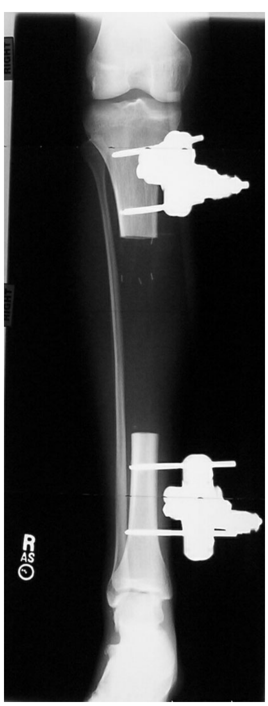

Fig. 3. Care of Patient 16 (Table II). After 17 cm tibia resection stabilized in an external fixator.

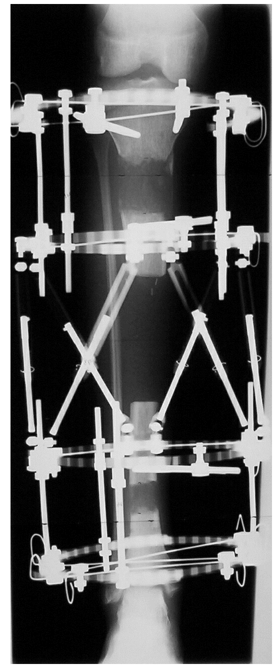

Fig. 4. Care of Patient 16 (Table II). Two months into trifocal bone transport.

The most common problem seen in our series was pin tract infections; however, our rates of pin tract infection was similar to that reported in previous studies [7,11,16,19,20,24–26] and not unexpected given the duration of fixation required to complete the required reconstructions. These infections are rarely a source of significant morbidity and typically amenable to oral antibiotic therapy. We found one incidence of osteomyelitis from these infections and no deep tissue infections, in addition, the end result for the patients despite a course involving a pin tract infection was overwhelming satisfactory as seen by our clinical measurements. As such, despite the extended use of external fixation, we believe the Ilizarov method carries minimal morbidity and is well tolerated by patients.

The primary limitation in our study lies in our sample size and in the retrospective data collection. Although a prospective design may have strengthened this study the relative rarity of the pathology addressed and the treatment method used make it of interest to the orthopedic and oncology community. Additionally, the generalizability

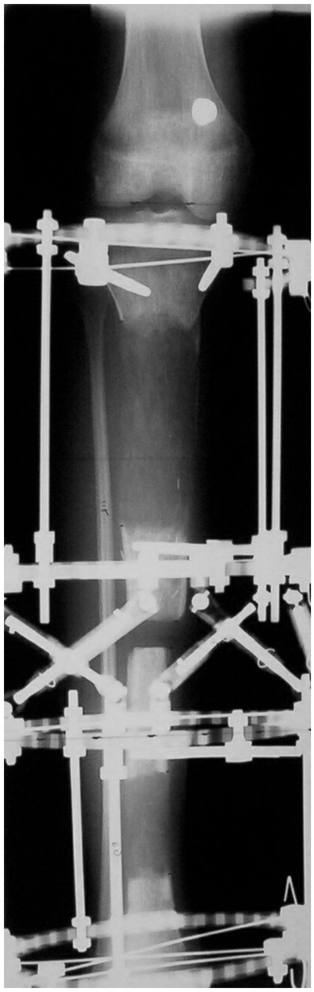

Fig. 5. Care of Patient 16 (Table II). Three months into trifocal bone transport.

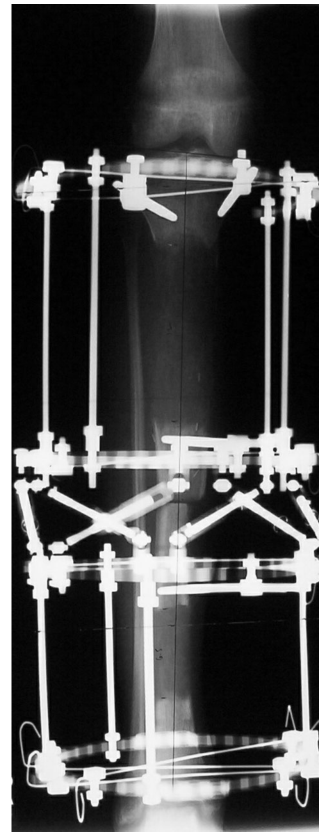

Fig. 6. Care of Patient 16 (Table II). Four months into trifocal bone transport with fragments docked.

of this study is limited by the exclusion of patients receiving chemotherapy. Our series is limited to patients who were not receiving chemotherapeutic agents during reconstruction; therefore, we cannot comment on the efficacy of distraction osteogenesis in patients on concurrent chemotherapeutic agents. It is possible that bone marrow suppression and immune compromised states caused by chemotherapy will thwart bone regeneration as well as increase the rates of pin site infections. Tsuchiya evaluated the use of external fixators during concurrent chemotherapy and reported 11/17 patients with pin site infections and one case that progressed to osteomyelitis [18]. High quality studies of this patient population are difficult because of the heterogeneous soft tissue quality and chemotherapy history and previous radiation exposures any of which may adversely affect outcomes.

CONCLUSIONS

The Ilizarov method is a safe means of limb reconstruction in the setting of primary or secondary reconstruction of bone tumors. Limb lengthening, bone transport, repair of nonunion, and correction of deformity can be comprehensively accomplished with this approach. Pin tract infection was the most common complication noted, but was typically amenable to treatment with oral antibiotics. Although

Fig. 7. Care of Patient 16 (Table II). Ten months after surgery with patient standing in frame and ambulating without aids.

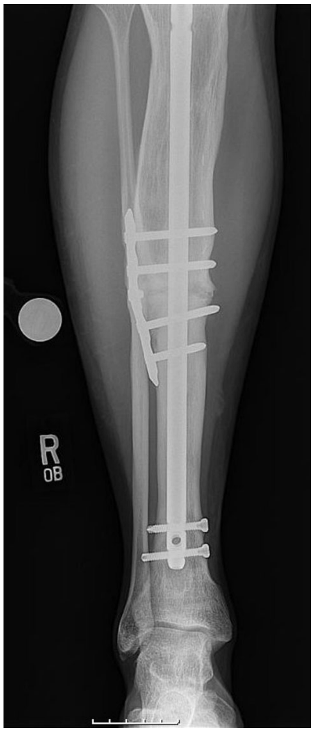

Fig. 8. Care of Patient 16 (Table II). Intramedullary rod and plate was needed to achieve bony union at docking site.

the success of distraction osteogenesis during concurrent chemotherapy is not known, the Ilizarov method offers a way of reconstructing large bone defects without a prohibitive risk of complications and thus offers an attractive route to limb salvage in place of amputation.

Fig. 9. Care of Patient 16 (Table II). Three-year follow-up, ambulating and playing sports without limitation.

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