Distraction osteogenesis technique using an intramedullary nail and a monolateral external fixator in the reconstruction of massive postosteomyelitis skeletal defects of the femur

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Background: Large skeletal defects due to postosteomyelitis are uncommon, and they present a challenging reconstructive problem. The aim of our study was to summarize our experience performing a distraction osteogenesis technique using an intramedullary nail and a monolateral external fixator in the reconstruction of massive postosteomyelitis skeletal defects of the femur.

Methods: Between January 1998 and October 2004, 17 patients with massive postosteomyelitis skeletal defects of the femur (11 men and 6 women), underwent the reconstruction procedure. After osteotomy of diaphysis of the femur, we inserted an intramedullary nail into the femur, and we placed a monolateral external fixator with half-pins lateral to the nail. Lengthening was started on the seventh postoperative day at a rate of 1 mm/d. Once we achieved solid bone union, we removed the monolateral external fixator; the intramedullary nail remained for bone consolidation until reconsruction was complete. We assessed the outcomes clinically and radiographically at a mean of 70.3 months postoperatively.

Results: At follow-up (mean 70.3, range 14.0–96.0 mo), all the skeletal defects were filled, bone union at docking sites was achieved without bone graft and leg length discrepancies were less than 2.5 cm in all patients. The mean gain in length was 12.9 (range 10.2–18.4) cm. According to Paley and Maar's evaluation criteria, we graded the bone results as excellent for 10 patients, good for 5, fair for 1 and poor for 1. We graded the functional results as excellent for 12 patients, good for 4 and fair for 1. The mean external fixator index was 18.1 d/cm; the consolidation index was 35.7 d/cm. Ten patients experienced pin infection, and 1 patient experienced a recurrence of deep infection. There were no neurologic or vascular injuries.

Conclusion: Our study demonstrates that a distraction osteogenesis technique using an intramedullary nail and a monolateral external fixator is a reliable method for the reconstruction of massive postosteomyelitis skeletal defects.

Contexte : Les lacunes osseuses majeures consécutives à une ostéomyélite sont rares et causent des problèmes de reconstruction difficiles. Notre étude visait à résumer notre expérience d'une technique d'ostéogénèse par distraction utilisant un clou intramédullaire et un fixateur externe monolatéral pour reconstruire des lacunes osseuses massives du fémur consécutives à une ostéomyélite.

Méthodes : Entre janvier 1998 et octobre 2004, 17 patients ayant des lacunes osseuses massives du fémur consécutives à une ostéomyélite (11 hommes et 6 femmes) ont subi une intervention de reconstruction. Après une ostéotomie de la diaphyse du fémur, nous avons introduit un clou intramédullaire dans le fémur et mis en place un fixateur externe monolatéral avec des demi-broches posées latéralement au clou. On a commencé l'allongement le septième jour après l'intervention à raison de 1 mm/j. Après la fusion solide de l'os, nous avons enlevé le fixateur externe monolatéral. Le clou intramédullaire est demeuré en place pour la consolidation de l'os jusqu'à ce que la reconstruction soit terminée. Nous avons évalué les résultats par des examens cliniques et radiographiques 70,3 mois en moyenne après l'intervention.

Résultats : Au suivi (moyenne de 70,3, intervalle de 14,0 à 96,0 mois), toutes les lacunes osseuses étaient comblées, la fusion de l'os au site d'amarrage s'était produite sans greffe osseuse et la différence au niveau de la longueur des jambes était inférieure à 2,5 cm chez tous les patients. L'allongement moyen s'est établi à 12,9 (intervalle de 10,2 à 18,4) cm. Selon les critères d'évaluation de Paley et Maar, nous avons jugé les résultats osseux excellents chez 10 patients, bons chez 5, moyens chez 1 et médiocres

chez 1 autre. Nous avons jugé les résultats fonctionnels excellents chez 12 patients, bons chez 4 et moyens chez 1. L'indice moyen du fixateur externe était de 18,1 j/cm, l'indice de consolidation s'est établi à 35,7 j/cm. Dix patients ont eu une infection aux broches et un patient a été atteint d'une infection profonde répétitive. Il n'y a pas eu de traumatisme neurologique ou vasculaire.

Conclusion : Notre étude démontre qu'une technique d'ostéogénèse par distraction utilisant un clou intramédulaire et un fixateur externe monolatéral constitue une méthode fiable de reconstruction de lacunes osseuses massives consécutives à une ostéomyélite.

Hematogeneous osteomyelitis is rarely seen in the femur; however, it may lead to poor outcomes owing to delayed or inappropriate treatments, especially in developing countries. Some severe chronic osteomyelitis may lead to nonunion and massive skeletal defects caused by procedures such as radical débridement, sequestrectomy, osteonecrosis or osteolysis. In children, if the physis is affected growth arrest can lead to discrepancies in the length of their legs, and this discrepancy can become larger each month as the children grow.

Massive skeletal defects resulting from postosteomyelitis are uncommon, and they present a challenging reconstructive problem. For such defects, several methods have been reported. Fowles and colleagues[1] described 21 children with a defect of the tibial shaft due to acute hematogenous osteomyelitis: 4 patients had spontaneous regeneration of the shaft, 11 had a posterior tibiofibular graft and 6 had a transfer of ipsilateral fibular disphysis. All the grafts united, and the children were able to lead normal lives. Kucukkaya and colleagues[2] described 7 patients with bone defects due to childhood osteomyelitis; the defects were treated with the Ilizarov method, with excellent functional and radiologic results after 4 years. Saridis and colleagues[3] described 13 patients with infected nonunion of the distal femur and bone loss; they had received radial surgical débridement and the Ilizarov external fixator. According to Paley and Maar's evaluation system, 8 of these patients had excellent clinical and radiological outcomes and 7 had excellent or good functional results.

Our study is a retrospective review of 17 patients with massive skeletal defects of the femur due to postosteomyelitis treated with a distraction osteogenesis technique using an intramedullary nail and a monolateral external fixator.

Methods

Participants

Between January 1998 and October 2004, 17 patients (11 men and 6 women) with massive postosteomyelitis skeletal defects of the femur underwent the reconstruction procedure: a distraction osteogenesis technique using an intramedullary nail and a monolateral external fixator.

Using standard diagnositic clinical, imaging and laboratory investigations, we confirmed the presence or absence of underlying osteomyelitis in all patients. If osteomyelitis was not present, we performed débridement and administered appropriate antibiotics to achieve a healthy soft-tissue bed. Before proceeding with the skeletal reconstruction, we confirmed that osteomyelitis had been controlled for at least 6 months in all patients, and we confirmed that results of laboratory tests, including leukocyte count, erythrocyte sedimentation rate and C-reactive protein, were normal.

We obtained preoperative radiographs to assess the skeletal defect, leg length discrepancy (LLD) and the diameter of the medullary canal before we proceeded to plan the reconstruction.

Surgical technique

Patients were supine on a radiolucent table with their limbs in a scissor position and a bolster below the pelvis on the involved side. We opted not to remove the sclerous bone ends in our study. We performed antegrade reaming over an intramedullary guide-wire to achieve a diameter 1.5 mm larger than that of the planed intramedullary nail. We then completed the osteotomy with an osteotome using multiple wire holes. We inserted and locked the intramedullary nail distally, with the excess length of the nail left proximally in the soft tissue. With the assistance of an image intensifier, we inserted 1 or 2 pins 4.5 mm above and below the level of osteotomy. We fixed all pins at the same plane with at least 1 mm between pins and the intramedullary nail to prevent medullary infection triggered by a pin-site infection.[4] We then applied a monolateral external fixator (The Third Medical Instrument Company, Wujin, China; Fig. 1) for lengthening.

Patients began daily physical therapy 2 days after surgery to maintain the range of motion of the hip and the knee. In addition to 1 hour of therapy per day with a physical therapist, the patients performed range-of-motion exercises for the hip and knee joints. Only touch-down weight-bearing with crutches was permitted. The amount of weight-bearing increased depending on the quality of regenerated bone observed on follow-up radiographs. We encouraged full weight-bearing after radiographs confirmed the regeneration of at least 3 of 4 cortices.

We began distraction 7 days after surgery at a rate of 0.25 mm 4 times daily. We adjusted the rate according to discomfort, swelling of the leg and quantity of regenerated

bone. During lengthening, we obtained anteroposterior and lateral radiographs to monitor bone regeneration and to measure and record the skeletal defect and LLD. We then adjusted the lengthening rate, target length and the deformity that occurred during lengthening. We recorded ranges of knee and hip movement and neurologic status on both sides preoperatively, postoperatively, during distraction and at the latest follow-up. Pin care was limited to daily showers; if there were signs of pin-site infection (i.e., redness, tenderness), we started antibiotics immediately. After docking, we continued distraction to correct LLD, and we applied compression to the docking site to stimulate bone union. We removed the monolateral external fixator only after radiographs confirmed the regeneration of at least 3 of 4 bone cortices and that bone union was achieved at the docking site. Patients had casts for 4 weeks after we removed the external fixators.

Evaluation criteria

We divided the results into bone and functional categories based on a modification of the evaluation system previously reported by Paley and Maar.[5] Bone results were based on 5 criteria: union, infection, deformity, LLD and the cross-sectional area of union of the regenerated bone and the docking site. An excellent bone result was one that had no evidence of infection, a deformity of 5° or less in any plane, an LLD of less than 2.5 cm and a bone union wide enough not to require long-term bracing or protection. A good result was union without infection and failure to meet 1 of the other criteria. A fair result was union without infection and failure to meet 2 of the other criteria; we considered patients to have achieved a fair result if they required long-term post-treatment bracing or protection for a low cross-sectional area of union of either the regenerated bone or the docking site. A poor result was nonunion and/or persistent or recurrent infection.

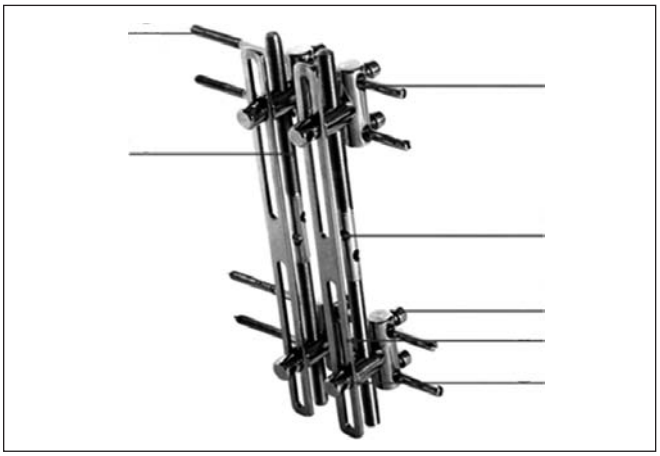

Fig. 1. A 2-segment monolateral external fixator. The monolateral external fixator is composed of 2 screw rods and link rails. It is a stable rectangular plane fixator, which is connected with bone by the link rails to form a polyrectangular structure. When the bone is elongated or compressed, the press board is removed. An S needle is used to rotate through the modulating hole in the middle of the screw rod in the external fixator. A bidirectional screw rod displaces the T-shape structure and elongates or compresses the bone by the link rails, leading to the elongation of the bone, pressed and stable. Image published with permission of the Third Medical Instrument Company.

The functional results were also based on 5 criteria: pain, need for walking aids or braces, hip or knee deformity or contracture, loss of range of hip and knee motion compared with the preoperative range and ability to return to normal activities of daily living (ADL) and/or work. An excellent functional result was one in which the patient had no pain or mild pain (not requiring narcotics), did not require a walking aid or brace, did not have hip and/or knee contracture greater than 5°, did not lose more than 20° of motion at the hip and/or knee joints compared with the preoperative range of motion and was able to perform all previous ADL without difficulty. A good result was one in which the patient had mild or no pain, was able to perform almost all ADL with minimal difficulty and failed to meet 1 of the other criteria. A fair result was one in which the patient had mild or no pain, was able to perform most ADL with minimal difficulty and failed to meet 2 of the other criteria. A poor result was one in which the patient had substantial pain (requiring narcotics), was markedly limited in ADL or who failed to meet 3 of the other criteria.

We considered the primary outcome to be the healing of the bone in the distraction gap and the bridging of 3 of 4 cortices on anteroposterior (AP) and lateral radiographs. The time of consolidation refers to the lapse from the surgery to the primary outcome, including the distraction and consolidation phases. We calculated the radiological consolidation index, which is the time of consolidation per centimeter of the distraction gap. We calculated the external fixation index by dividing the number of days of external fixation by the total amount of bone transported and/or the amount of lengthening in centimeters.

RESULTS

Participants

We included 17 patients with a mean age of 24 (range 17–32) years. Patient characteristics are described in Table 1. All patients had hematogenous osteomyelitis, and had collectively undergone 53 previous surgeries (mean 3/person, range 1–7/person), including radical débridement, cancellous bone graft and vascularized bone graft. However, all surgeries had ultimately failed.

Each patient arrived at our hospital with an apparent bone defect at the diaphysis of the femur (mean 11.3, range 8.0–18.4 cm). According to Paley's classification of nonunion,[6] each patient had a type B3 nonunion. The patients had severely limited range of motion of the knee; in 3 patients, the knee joint was completely stiff. There was

moderate to severe disuse osteopenia of the distal femoral fragment in all patients; no patient was able to bear weight. The mean time from onset of hematogenous osteomyelitis to our surgery was 5.5 (range 4.0–9.0) years.

At a mean follow-up of 70.3 (range 24.0–96.0) months, the skeletal defects were filled, bone union at the docking sites was achieved without bone graft and the LLD was less than 2.5 cm in all patients. All the patients were satisfied with the functional and cosmetic outcomes of their surgeries. The mean gain in length was 12.9 (range 10.2–18.4) cm. The mean external fixator index was 18.1 d/cm; the consolidation index was 35.7 d/cm. According to Paley's evaluation criteria, bone results were excellent in 10 patients, good in 5, fair in 1 and poor in 1 (Table 2). Functional results were excellent in 12 patients, good in 4 and fair in 1 (Table 3).

Table 1. Patient characteristics

Patient no.	Age, yr	Sex	No. previous surgeries	Skeletal defect, cm	Length achieved, cm	External index, d/cm	Consolidation index, d/cm
1	19	F	2	11.3	11.4	15.3	31.8
2	28	M	3	11.6	12.0	15.8	33.2
3	23	M	2	10.2	10.5	12.4	28.4
4	19	F	4	14.7	15.0	21.3	40.1
5	25	M	2	12.1	12.0	18.5	38.0
6	32	M	3	13.2	13.0	18.1	36.9
7	27	F	4	14.7	15.1	19.5	41.2
8	20	M	3	15.8	15.0	23.4	39.5
9	17	F	4	18.4	18.0	24.3	51.6
10	26	M	1	10.7	10.9	15.9	30.7
11	28	M	3	12.9	13.0	18.7	32.4
12	21	F	3	10.6	10.5	14.8	29.3
13	26	M	5	11.8	12.0	17.6	31.9
14	24	M	4	13.4	13.0	19.3	37.8
15	21	M	2	12.0	12.0	17.2	35.0
16	23	F	3	11.4	11.2	15.6	29.5
17	29	M	3	15.1	15.0	20.4	39.0
Mean	24	—	3	13.2	13.3	18.1	35.7

Complications

Using Paley's classification,[7] we divided complications into problems, obstacles and true complications. Problems

Table 2. Bone results at the latest follow-up

Patient no.	Union	Infection	Deformity	Leg length discrepancy, cm	Regenerated bone and docking site	Grade
1	Yes	No	8°	0.8	Normal	Good
2	Yes	No	No	1.2	Normal	Excellent
3	Yes	No	No	0.7	Normal	Excellent
4	Yes	No	27°	0	Normal	Good
5	Yes	No	9°	1.5	Normal	Good
6	Yes	No	No	0.6	Normal	Excellent
7	Yes	No	No	0	Normal	Excellent
8	Yes	Yes	8°	1.7	Low cross-sectional area of union of regenerated bone	Poor
9	Yes	No	No	1.2	Low cross-sectional area of union of regenerated bone	Fair
10	Yes	No	No	0.4	Normal	Excellent
11	Yes	No	No	0.7	Normal	Excellent
12	Yes	No	No	0	Normal	Excellent
13	Yes	No	No	1.3	Normal	Excellent
14	Yes	No	8°	0	Normal	Good
15	Yes	No	No	0	Normal	Excellent
16	Yes	No	9°	1.7	Normal	Good
17	Yes	No	No	0.5	Normal	Excellent

Table 3. Functional results at the latest follow-up

Patient no.	Knee flexion		Contracture > 5° or deformity of hip or knee	Pain	Need for walking aids or braces	Ability to perform all previous activities of daily life	Grade
	Before surgery	At latest follow-up					
1	90°	85°	Absent	Absent	No	Yes	Excellent
2	120°	108°	Absent	Absent	No	Yes	Excellent
3	100°	92°	Absent	Absent	No	Yes	Excellent
4	70°	55°	Knee varus 27°	Absent	No	Yes	Good
5	Stiff	Knee varus 8°	Absent	No	Yes	Good	
6	90°	85°	Absent	Absent	No	Yes	Excellent
7	110°	95°	Absent	Absent	No	Yes	Excellent
8	90°	75°	Contracture 10°, knee valgus 8°	Absent	Yes	Yes	Fair
9	Stiff	Absent	Mild	Yes	Yes	Good	
10	75°	65°	Absent	Absent	No	Yes	Excellent
11	80°	75°	Absent	Absent	No	Yes	Excellent
12	80°	70°	Absent	Absent	No	Yes	Excellent
13	Stiff	Absent	Mild	No	Yes	Excellent	
14	80°	75°	Absent	Absent	No	Yes	Excellent
15	110°	100°	Absent	Absent	No	Yes	Excellent
16	90°	80°	Knee varus 9°	Absent	No	Yes	Good
17	90°	85°	Absent	Absent	No	Yes	Excellent

referred to minor complications treated nonsurgically, obstacles referred to complications that were resolved with surgery, and true complications referred to residual permanent deficits at the end of the treatment period (Table 4).

Superficial pin-tract infection was the most frequent complication (n = 10); it was successfully treated in all 10 patients with local care and oral antibiotics and resolved at all pin sites. Two patients reported severe pain and required oral analgesics during lengthening; we graded pain as mild after we removed external fixators. Angulation deformities greater than 5° at the docking site developed in the femurs of 7 patients after removal of the frame. None of these patients received additional treatment because they all could walk well and accepted the results. We observed knee contracture in 5 patients. In 4 of these patients, the contracture resolved through functional exercises under the guidance of a physiotherapist. One patient (patient 8) had a true complication: contracture of 10° due to deep infection. We observed delayed consolidation in 2 patients; this was resolved with autologous cancellous bone grafts. Deep intramedullary infection, confirmed by specimens taken when the nail was removed, occurred in 1 patient after successful lengthening. After reaming of the medullary canal, we applied another external fixator for bone consolidation, and we administered antibiotics intravenously. There were no neurologic or vascular injuries, and no fractures of the new bone in the distraction gap occurred after removal of the external fixator.

Discussion

Massive skeletal defects resulting from postosteomyelitis are uncommon, and they present a challenging reconstructive problem for any orthopedic surgeon. Knowledge and skill on the part of the the surgeon and hospital resources are required to successfully face the challenge. Amputation is often unacceptable to patients and their families; they prefer limb-salvage procedures, which often include cancellous bone grafts, allografts, vascularized bone grafts and distraction osteogenesis.

For many years, the most common treatments for skeletal defects were autologous cancellous bone graft and vascularized bone graft. Autologous cancellous bone graft is effective for small defects; however, when the defect is massive, the bone graft will not be enough to fill the defect. The process of graft incorporation and corticalization (creep substitution) to support body weight is lengthy and may never be completed. In our study, most patients underwent cancellous bone grafts before presenting to our hospital, but the bone was absorbed at final outcome. Vascular bone grafting has been prooven useful in overcoming massive bone defects.[8–11] Takami and colleagues[8] reported using free vascularized fibular grafts in 7 patients with large tibial defects following trauma or tumour resection. Patients were observed for more than 5 years; tibial union and excellent functional results were achieved in all 7. However, healing and remodelling of bone graft is lengthy; osteopenia and joint stiffness due to prolonged remodelling may occur. Refracture and host–graft junction healing problems are another common complication with this type of grafting technique. Futhermore, if the fibula is too thin to support weight-bearing, this would limit the application of the technique to the femur.

Currently, the Ilizarov method of callus distraction and segmental bone transport has been shown to be an exciting new method for the treatment of LLD, deformity, nonunion and osteomyelitis.[12–15] Some orthopedic surgeons also report using this technique in combination with the Ilizarov frame for massive skeletal defects.[5,16–18] Saridis and colleagues[3] described 13 patients with infected nonunion of the distal femur and bone loss who had been treated by radical surgical débridement and the Ilizarov external fixator. According to Paley's grading system, 8 of these patients had excellent clinical and radiological results and 7 had excellent and good functional results. Abdel-Aal and colleagues[16] reported good results for 15 patients with massive tibial defects treated with Ilizrov external fixators. Paley and colleagues[5] described 19 patients with tibial bone defects treated by the Ilizarov bone transport method. After a mean follow-up of 6.5 years, union was achieved in all cases; the bone results were excellent for 15 patients, good for 3 and fair for 1. The functional results were excellent for 12 patients, good for 6 and poor for 1. In contrast to conventional methods, the Ilizarov technique can address not only the bone defect, but also the associated problems of shortening, deformity, soft-tissue loss and joint contractures. However, the main disadvantage of the Ilizarov method is the lengthy external fixation time. It can be poorly tolerated by patients and impose lengthy psychosocial hardships on patients and their families. In addition, there is a higher incidence of complication.

To reduce the external time during lengthening, some physicians have previously performed distraction osteogeneous using an intramedullary nail and an external fixator. Raschke and colleagues[19] first reported this technique, which they performed for 4 patients who had

Table 4. Incidence of problems, obstacles and true complications

Difficulty	No. patients	Problems	Obstacles	True complications
Pin-tract infection	10	10	—	—
Deep intramedullary infection	1	—	1	—
Severe pain	2	2	—	—
Knee contracture	5	4	—	1
Delayed consolidation	2	—	2	—
Angular deformity > 5°	7	—	7	—
Total	27	16	10	1
Complication rate, %	100	59	37	4

post-traumatic bony defects. The defects had been treated by bone transport using a monorail distraction system composed of an unreamed intramedullary nail and a unilateral ankle orthosis distraction device. Transport was achieved in all patients without angular or rotational deformity or LLD. Kocaoglu and colleagues[20] described 13 patients with segemental bone defects due to chronic osteomyelitis, which they treated with bone transport using external fixators and intramedullary nails. At a mean follow-up of 47.3 months, 11 of the 13 patients had an excellent result in terms of both bone and functional assessment.

Some authors have compared this monorail technique with the Ilizarov technique.[21,22] Paley and colleagues[21] compared results for 29 patients who underwent leg lengthening over an intramedullary nail with those for 31 patients who underwent standard Ilizarov femoral lengthening. They found that the average duration of external fixation was reduced by almost one-half in the intramedullary nail group, and that the consolidation index was reduced significantly. They concluded that femoral lengthening over an intramedullary nail is safe and reliable and that it offers some advantages, including a decrease in the duration of external fixation, protection against refracture and earlier rehabilitation.

Comparatively, in our study the mean external fixator index was 18.1 d/cm and the mean consolidation index was 35.7 d/cm. Our results differed slightly those of Kocaoglu's report: the mean external fixator index was 13.5 d/cm and the mean consolidation index was 31.7 d/cm.[20] We may have achieved these different results because we did not remove the external fixator until bone union was achieved at the docking site.

Nonunion at the docking site is a common complication of bone transport. In adult patients, bone grafting is recommended at the time of docking to prevent the common complication of nonunion; however, there is no evidence that bone grafting is necessary at the docking site. Kucukkaya and colleagues[2] described 7 patients with childhood chronic hematogenous osteomyelitis, none of whom underwent bone grafts at the docking site; no nonunion occurred. Dendrinos and colleagues[23] treated defects of the tibia in 28 patients using the Ilizarov bone transport method and compression at the docking site for bone union. Bone grafts were required in only 3 patients. In our study, we did not expose the docking site to freshen both bone ends and remove scar tissue. After docking, we continued distraction to correct LLD, and we applied compression to the docking site to stimulate bone union. To our surprise, all the docking sites achieved bone union quickly without bone graft (Fig. 2, Fig. 3 and Fig. 4). Furthermore, we observed obvious bone regeneration near the docking site in some patients (Fig. 3). We defined this as "periosteal dormancy phenomenon," likely associated with increased blood supply due to distraction or to the change in the local microenvironment of the periostea at the docking site, which may have activated bone formation. Further research on this phenomenon may be warranted.

Ilizarov[24] emphasized the importance of preserving the endosteal blood supply in distraction osteogenesis, and some authors have expressed concern that intramedullary nailing may compromise the endosteal blood supply of the diaphyseal bone,[25,26] thus affecting the quantity of bone regeneration and healing time. However, in a rabbit model Kojimoto and colleagues[27] demonstrated that the periosteum plays a more important role than the endosteum in the regeneration of distraction callus. Some clinical studies have also shown that osteotomy is as effective as corticotomy in the creation of the initial division of bone in lengthening. Brutscher and colleagues[28] reported that osteotomy and corticotomy are equally effective in dividing the bone and that neither procedure affects subsequent healing of the lengthened segment. Moreover, there is evidence that the periosteal blood supply increases after intramedullary nailing,[29,30] and this is valuable for effective distraction osteogenesis. In our study, distraction osteogenesis over the intramedullary nail compromised neither the quality nor quantity of the regenerated bone; abundant new bone was produced despite the fact that we reamed all the medullary canals.

In our study, superficial pin-tract infection was less severe than in other studies in which lengthening was performed with the Ilizarov frame. This difference may be explained by the decreased duration of external fixation and the careful pin care in our study; once there were any signs of pin-tract infection (i.e., redness and tenderness), we began antibiotic therapy immediately. Unfortunately, we observed deep infection in 1 patient even though we followed the precautions recommended by Paley and colleagues.[21] This rate of deep infection (5.9%) was lower than that reported in the study by Simpson and colleagues[31] (15%) and higher than that reported by Paley and colleagues[21] and Silberg and colleagues[32] (3%–5%). Our patient underwent 3 surgeries, including 2 cancellous bone grafts and 1 free vascularized fibular graft, and the length of bone formation is currently 15.8 cm. We administered intravenous antibiotics, immediately removed the nail and, after reaming the medullary canal, applied another bilateral external fixation. The final oucome for this patient was a poor bone result and fair functional outcome.

In conclusion, the distraction osteogenesis technique using an intramedullary nail and a monolateral fixator is an effective method of treating massive postosteomyelitis skeletal defects. However, physicians must be cautious with respect to deep infection.

Competing interests: None declared.

Contributors: Drs. Li and Zhang designed the study. All authors acquired the data, which Drs. Li and Zhang analyzed. Dr. Duan wrote the article, which all authors reviewed. All authors gave final approval for publication.

Fig. 2. A 17-year-old girl presented with nonunion and a skeletal defect 4 years after hematogenous osteomyelitis due to radical débridement, absorption and lysis of the right femur. (**A**) The preoperative photograph shows a 16.4-cm leg length discrepancy (LLD). Radiographs show (**B**) the 2-cm skeletal defect, (**C**) distraction and (**D**) bone union 2 years and (**E**) 3 years after surgery. Union at the docking site was achieved, but regenerated bone was not substantial enough for weight-bearing. Three years after surgery, the LLD is no longer apparent (**F**).

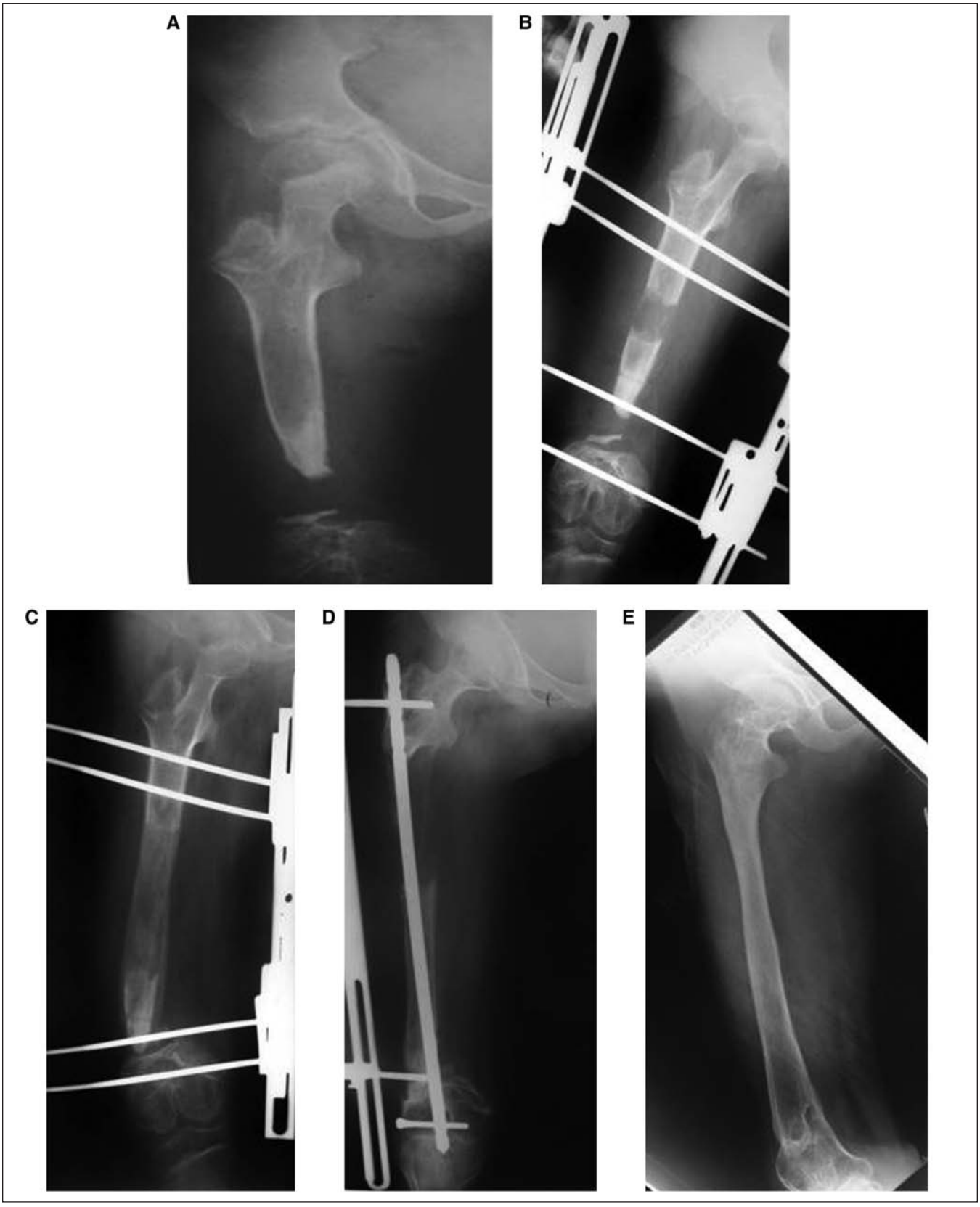

Fig. 3. A 19-year-old woman presented with nonunion and a skeletal defect 6 years after hematogenous osteomyelitis. She had a 2-cm skeletal defect and 14.6-cm leg length discrepancy (**A**). We performed distraction osteogenesis using an external fixator (**B**); however, an angulation of about 30° occurred at the distal femur (**C**), so we switched to a combined technique (**D**), and at the latest follow-up bone union with equal leg length was achieved (**E**).

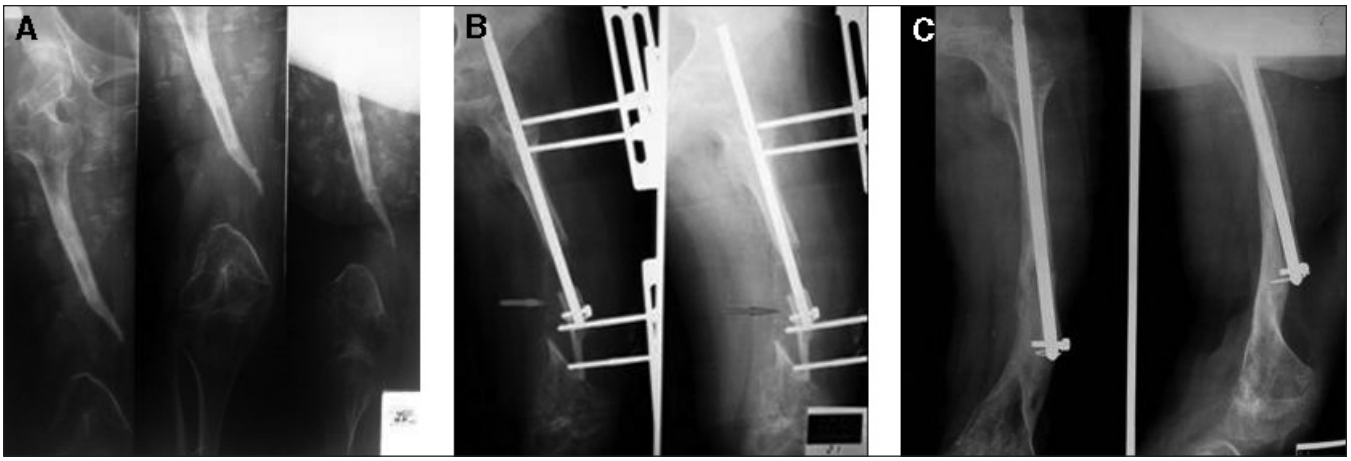

Fig. 4. An 18-year-old man presented with nonunion and a skeletal defect 5 years after hematogenous osteomyelitis. Radiographs show (**A**) a 2.5-cm skeletal defect with a leg length discrepancy of 12.2 cm, (**B**) obvious bone regeneration (arrow) at the docking site during distraction and (**C**) bone consolidation 10 months after surgery. Bone union at the docking site was achieved.

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