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Acute shortening versus bone transport for the treatment of infected femur non-unions with bone defects☆

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ABSTRACT

Background: The bone transport technique has been a well-known method in the treatment of osteomyelitis of the long bones with large segmental bone defects. However, one of the major drawbacks with this traditional technique is the long-lasting consolidation period, which may entail infectious and non-infectious complications. To overcome this drawback, several techniques were developed, one of which is acute shortening and re-lengthening. The aims of this study were: 1) to present our experience with a new modified technique of acute shortening and re-lengthening using a monolateral external fixator combined with a retrograde intramedullary nail, and 2) to compare its results with the classic Ilizarov bone transport method in the management of infected non-unions of the distal femur with bone loss.
Methods: This retrospective study compared these two techniques. 17 patients were treated using our modified technique of acute shortening and re-lengthening (Group A); 15 patients were treated using segmental bone transport (Group B). The average follow-up was 66 months (range: 24–180) in Group A and 70 months (range: 24–240) in Group B. The mean bone loss was 5.5 cm (range: 3–10) in Group A and 5.9 cm (range: 3–10) in Group B. The primary outcome of the present study was to compare the external fixator time (EFT) and external fixation index (EFI) between the two groups. The bone and functional status were also assessed.
Results: The mean EFI was lower in Group A (mean: 31.8 days/cm; range: 24–50) than in Group B (mean 48.7 days/cm; range: 40–100) ($p = 0.02$). The mean EFT was shorter in Group A (mean: 120 days; range: 100–150) than in Group B (mean: 290 days; range: 100–400) ($p = 0.0003$). With respect to the bone and functional results, no difference was observed.
Conclusions: Although both techniques could be employed safely in the treatment of infected non-union of the distal femur with size defects ranging between 3 cm and 10 cm, our modified technique of acute shortening and re-lengthening may confer greater patient satisfaction because of shorter EFI.

Introduction

Definitive treatment of chronic osteomyelitis of the long bones typically includes radical debridement of infected areas, and such patients generally received several surgical interferences, leading to serious bone and soft tissue damages and eventually considerable bone defects [1]. Although a multitude of treatment options are employed to eradicate long-lasting bone infections and to reconstruct defects of long bones, the treatment of osteomyelitis of the long bones remains a considerable challenge, even in the best hands [2].

Historically, distraction osteogenesis, described by Ilizarov [3], has been widely used as a salvage method for patients with large segmental bone defects. The Ilizarov technique offers the advantage of not only resolving the problem of the bone defect, but also any shortening, malalignment, joint contractures, or soft tissue loss. Nonetheless, the Ilizarov bone transport method is fraught with some potential drawbacks, including prolonged EFT and its associated complications such as infection, delayed maturation of the regenerate bone, and delayed union or non-union at the docking

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site [2]. By extension, in the management of segmental bone defects secondary to debridement of osteomyelitis, with an effort to reduce the EFT and relevant complications, several techniques have been recently developed. These are based on the Ilizarov philosophy and employed under the titles of acute shortening and re-lengthening [4–7] and combined techniques (lengthening over a nail, lengthening and then nailing, etc.) [8–10]. However, despite their favorable outcomes and some advantages, these methods suffer from various limitations implied in the current literature, including infection [8,9,11], knee stiffness [8], and the need for acute deformity correction (if present), as well as demanding and multistep surgical procedures.

Over the past decades, acute shortening and lengthening technique using a circular external fixator has been deployed in the treatment of long bone non-unions with bone loss [4–7]. We developed and used a novel technique for more than 10 years, which represents our modification of this well-known technique, in an effort to overcome the disadvantages of both the classic bone transport technique and combined techniques. The present study aimed to summarize our experience with this novel technique of acute shortening and re-lengthening using a monolateral external fixator combined with a retrograde intramedullary nail and to compare its results with the well-established Ilizarov bone transport method in the treatment of segmental defects and limb shortening secondary to radical debridement of infected non-union of the distal femur.

Patients and methods

The medical records of 40 consecutive patients in whom Cierny-Mader type-IVA and type-IVB chronic osteomyelitis of the distal femur [1] was diagnosed and treated from 2003 to 2014 at our institution were retrospectively reviewed. All patients were evaluated according to the eligibility criteria (inclusion and exclusion) given in Table 1. After excluding eight patients (one has a concomitant metabolic disease, two had a large bone defect (>10 cm), one was unable to come to follow-up appointments, one was over 60 years of age, one was a heavy smoker, two have a body mass index of more than 40), the remaining 32 patients who met the inclusion criteria were enrolled in the study and invited to a final follow-up examination for functional evaluation. Informed consent was obtained from all subjects, and the institutional review board approval was obtained prior to data collection.

Patients included in the study were divided into two groups: Group A and Group B. 17 (56%) patients (5 female, 12 male) were managed using the novel combined technique (Group A); 15 patients (46%) (5 female, 10 male) were managed using segmental bone transport technique (Group B). In group A, the underlying etiologies of the chronic osteomyelitis were a traffic accident in seven patients, falling down in 5, hematogenous infection in two, and a gunshot injury in three. In Group B, the etiologies were a traffic accident in six patients, falling down in four, a gunshot injury in three, and hematogenous infection in two.

The mean age of patients was 39 years (range: 26–56) in group A and 42 years (range: 28–58) in group B. The average follow-up was 66 months (range: 24–180) in group A and 70 months (range: 24–240) in group B. The mean number of the previous operations was 2.4 (range: 1–12) for group A and 2.5 (range: 1–11) for group B. The total bone loss was calculated as the previous bone defect plus the amount resected at surgery. The mean bone loss was 5.5 cm (range: 3–10) in group A and 5.9 cm (range: 3–10) in group B. Patients in either group were comparable in terms of the demographic data given in Tables 2 and 3 ($p > 0.05$ for age, number, duration of follow-up, the number of the previous operation, and the amount of total bone loss).

Clinical evaluation and outcome measures

The primary outcome of the present study was comparisons of the EFT and EFI between the two groups. The EFI was measured by

Table 1
Eligibility criteria of the study.

Eligibility Criteria	
Inclusion Criteria	**Exclusion Criteria**
➢ Having a diagnosis of infected distal femur non-union ➢ Having a bone loss of 3 to 10 cm ➢ A minimum of two-year follow-up ➢ Being willing to participate in the study	➢ Presence of a concomitant metabolic or malignant disease ➢ Having a large bone defect (>10cm) ➢ Having an irregular follow-up ➢ Being over 60 years old ➢ Being a heavy smoker
	➢ Having a body mass index of more than 40 ➢ Being unwilling to complete the questionnaires

Table 2
Demographic characteristics and outcomes in the acute shortening and re-lengthening group.

Patient	Age (years)	Follow-up (months)	Bone loss (cm)	Additional treatment	Current bone status		Current functional status	
					Union	Results	ROM	Results
1	53	24	6		union	excellent	full	excellent
2	47	36	7		union	excellent	full	excellent
3	32	34	5		union	excellent	full	excellent
4	43	40	3	Bone graft	union	fair	full	good
5	30	32	7		union	excellent	full	excellent
6	32	36	4		union	good	full	excellent
7	26	180	4		union	excellent	full	good
8	28	108	8		union	good	full	excellent
9	46	56	3		union	excellent	full	good
10	33	90	4		union	good	full	excellent
11	56	72	4		union	excellent	full	excellent
12	43	60	3		union	excellent	full	excellent
13	45	60	8		union	fair	full	good
14	46	56	10		union	excellent	full	excellent
15	34	52	5		union	excellent	Knee flexion contracture of 10°	fair
16	44	66	5		union	good	Full	good
17	36	48	8		union	excellent	Knee flexion contracture of 5°	fair

Table 3
Demographic characteristics and outcomes in the segmental bone transport group.

Patient	Age (years)	Follow-up (months)	Bone loss (cm)	Additional treatment	Current bone status		Current functional status	
					Union	Results	ROM	Results
1	48	40	5		union	excellent	full	excellent
2	32	56	6		union	excellent	full	excellent
3	53	34	7	bone graft	union	fair	Knee flexion contracture of 5°	good
4	43	24	3		union	excellent	full	excellent
5	34	28	7		union	excellent	full	excellent
6	43	36	8	bone graft	union	good	full	good
7	28	90	6		union	excellent	full	good
8	30	96	5		union	excellent	full	excellent
9	40	240	4	bone graft	union	good	Knee flexion contracture of 5°	good
10	38	72	6		union	good	full	excellent
11	58	96	5		union	excellent	full	excellent
12	48	60	4	bone graft	union	good	full	excellent
13	44	56	7		union	good	Knee flexion contracture of 15°	fair
14	40	58	10		union	excellent	full	excellent
15	38	50	5		union	excellent	Knee flexion contracture of 15°	good

dividing the total EFT in days by the total amount of lengthening or the total amount of bone transported.

The bone and functional status were assessed using the criteria of Paley et al [12]. Bone results were categorized as excellent, good, fair, or poor and functional results as excellent, good, or fair.

Complications encountered in both groups were categorized according to the system of Paley [13], involving problems, obstacles, or sequelae.

Preoperative planning

In the preoperative period, all patients were evaluated in terms of local skin infection and ischemia, deformity, shortening, the neurovascular status of the affected limb, joint function, and nutritional status. Magnetic resonance imaging was applied to examine the whole femur and detect any skipped or distant infection as well as any necrotic bone area. CT angiography was performed to exclude any vascular damage from previous surgical interventions.

Infection management: resection, antibiotic administration, and microbiological evaluation

In both groups, a two-stage treatment was carried out. In the first stage, if present, the previous implant was initially removed. Then, cultures from the infected area of the bone were taken, and radical resection of the dead bone with debridement of infected soft tissue was carried out. After bone and soft tissue resection, the dead space was filled up with custom-made antibiotic beads (a combination of 40 g polymethylmethacrylate powder and 2.4 g of teicoplanin). Until the second stage of the operation, all patients were immobilized using a temporary monolateral external fixator.

The cultures were positive in all cases from either group. In group A, *methicillin-resistant Staphylococcus aureus* was isolated in seven patients, a methicillin-sensitive *Staphylococcus aureus* in six, and *Pseudomonas aeruginosa* in four. In group B, a methicillin-resistant *Staphylococcus aureus* was isolated in eight patients, a methicillin-sensitive *Staphylococcus aureus* in five, and *Pseudomonas aeruginosa* in two. In all cases, IV antibiotics were administrated according to the sensitivities and cultures for a minimum of six weeks or until the level of the C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR) had returned to normal.

Once the levels of the CRP and ESR returned to normal, the second stage of the operation was initiated in both groups. After removal of the antibiotic-impregnated beads, a minimum of three biopsies were obtained from the bone gap and sent for gram staining and frozen-section analysis. If no micro-organisms were identified by gram staining and there was a cut-off point of less than 3 to 4 polymorphonuclear leukocytes per high-power field, the infection was considered to be cured. After this microbiological confirmation was achieved in all cases, the reconstruction surgery was completed.

Surgical techniques

The novel combined technique

In the second stage of the operation, after re-debridement of the involved area, the acute shortening of the bone defect was performed in all cases of group A. At this point, we checked the distal arterial circulation by palpation of the dorsalis pedis and posterior tibial pulses, assessment of capillary refill in addition to, and measurement of the oxygen saturation of the great toe and Doppler ultrasound. If the circulation was disturbed following the shortening, the femur was re-lengthened until the circulation returned to normal. Subsequently, in an attempt to increase the stability of the docking site and therefore to prevent non-union and mal-union, we implanted a reamed retrograde femoral nail (Synthes®, Oberdorf, Switzerland) that is as short and large as possible through the intercondylar notch of the femur. After the nail was locked with two proximal and two distal locking screws, a monolateral external fixator (Tasarım medical®, Istanbul, Turkey) was mounted on the femur using proximal, middle, and distal pins, respectively. Finally, a lengthening osteotomy was performed in the proximal third of the femur by the use of the multiple-drill-hole technique with further cortical chiseling (Fig. 1. A–I).

The segmental bone transport

The classic four-ring Ilizarov frame that is connected with rods was applied to the involved femur under fluoroscopic control, since the system must permit sliding for either internal or external segment transport. Internal segment transport was preferred in one patient whose defects were larger than 8 cm. When external transport was performed, all rings were affixed to the bone using Schanz pins and K-wires (Fig. 2. A–G).

Postoperative management

On the second postoperative day, while patients in the group A were allowed partial weight bearing with two crutches until the

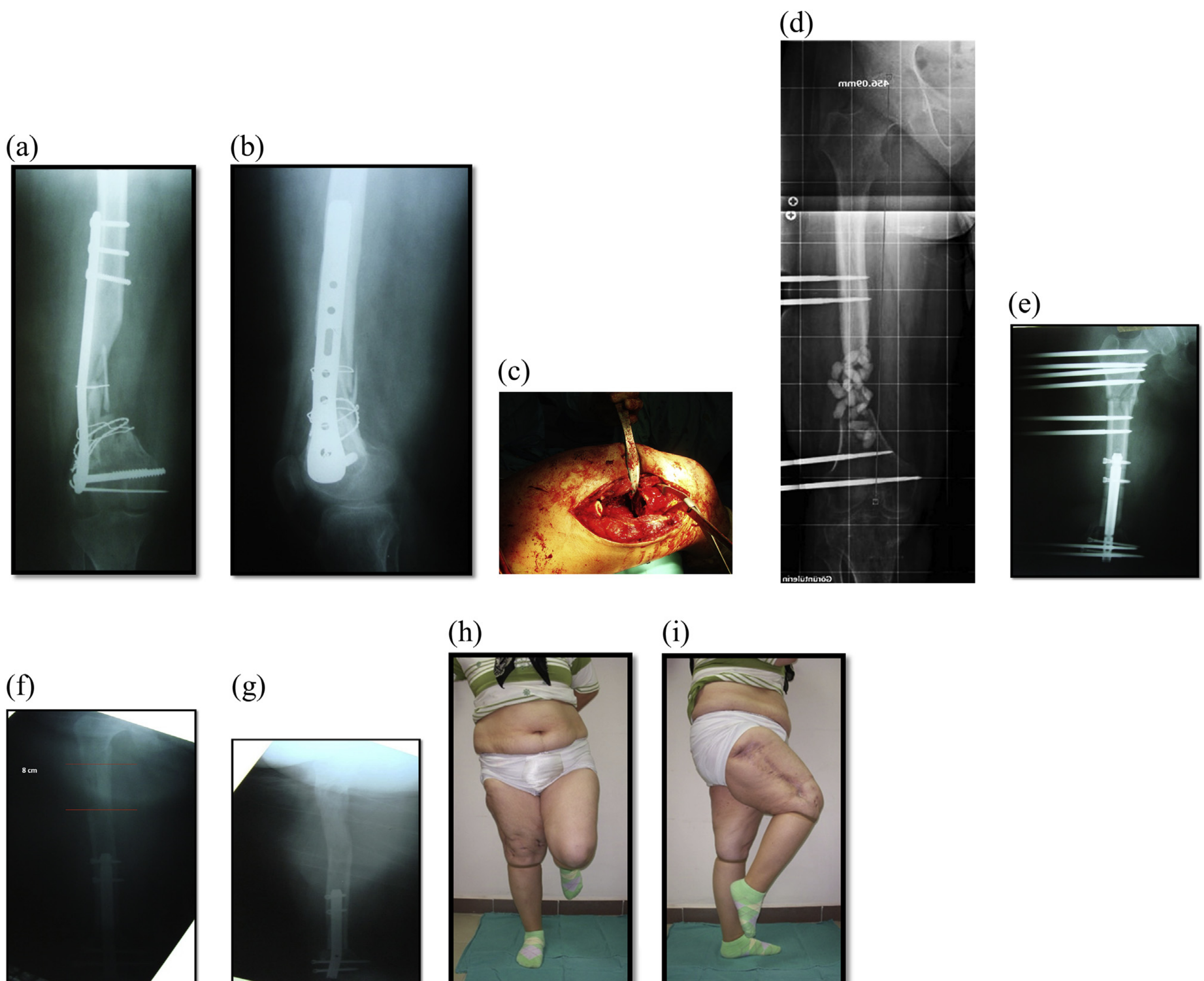

Fig. 1. Follow-up radiographs and clinical views of a patient who underwent the acute shortening and re-lengthening with the novel combined technique. Preoperative anteroposterior (AP) and lateral X-rays show an infected non-union of the distal femur **(A–B).** The intraoperative clinical view illustrates resection of the non-union zone and **(C)**, the immediate postoperative AP X-ray shows temporary fixation with a monolateral fixator **(D).** The immediate postoperative X-ray demonstrates acute compression, stabilized by a retrograde nail, and a lengthening osteotomy combined with a monolateral external fixator **(E).** The final AP and lateral X-rays show a lengthening of 8 cm after removing the fixator **(F–G).** The most recent clinical images display the patient with non-limb length discrepancy **(H–I).**

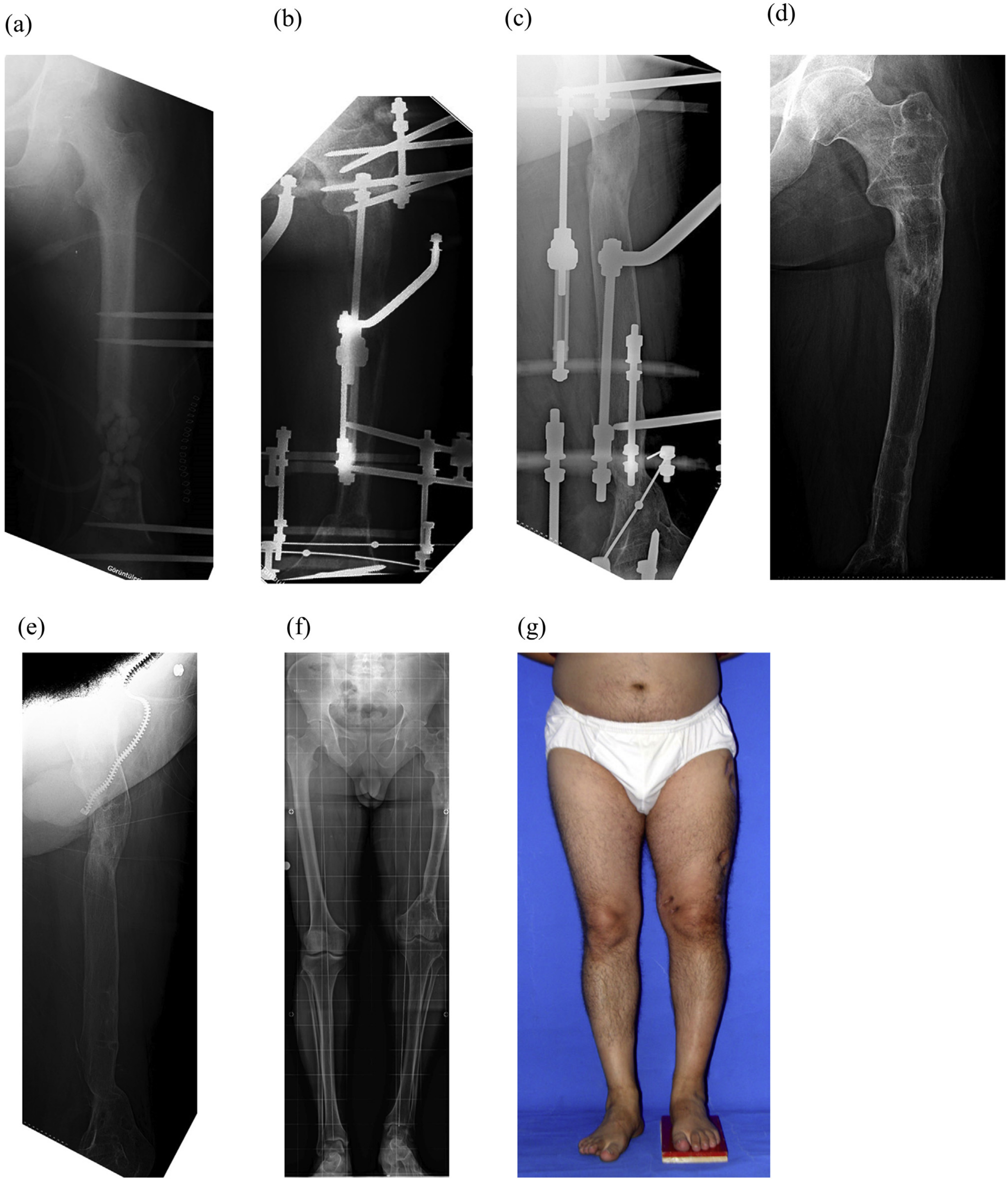

Fig. 2. Follow-up radiographs and clinical views of a patient who underwent the segment transport with Ilizarov type circular external fixator. The X-ray demonstrates resection of the non-union zone **(A).** AP and lateral X-rays illustrate docking of the segment at distal and consolidation of the proximal part **(B–C).** The final radiographs **(D-E-F)** and clinical image **(G)** show the patient with a limb length discrepancy of 3 cm after the end of treatment.

consolidation at the regenerate site was achieved, full weight bearing was recommended in the group B.

An epidural catheter was inserted for postoperative pain management, and range of motion exercises of the knee and hip were started as soon as pain permits in the postoperative period.

All patients in each group received parenteral and oral antibiotic therapy, according to culture results. Additionally, for the care of the pin sites, cleaning with a saline solution was performed every two days for the care during the period of distraction.

In all patients, the lengthening through the osteotomy site was commenced at a quarter turn four times per day following a latency period of seven days, and all patients were monitored in outpatient clinics every 2 weeks during the distraction and

Table 4
Details of the complications (according to the system of Paley) encountered during the treatment period.

Complications	Number of complications		Number of patients		Complication rate (%)	
	Group A	Group B	Group A	Group B	Group A	Group B
Problems	9	14	9	12	50	40
Grade-II pin-track infection	1	2	1	2	5	5
Translation/angulation at regenerate site	2	2	2	3	10	5
Delayed maturation of regenerate site		3				10
Transient loss of knee movement						
Transient loss of ankle movement						
Total	12	21	12	17	65	60
Obstacles	3	3	2	3	20	10
Grade-III pin- track infection	1	4	1	4	5	15
Soft tissue invagination						
Bone grafting						
Equinus deformity						
Total	4	7	3	7	25	25
Sequelae	1	3	1	3	5	10
Malalignment > 5°	1	2	1	2	5	5
Knee contracture > 5°						
Total	2	5			10	15
Overall total	18	33	1	5	100	100

monthly during the consolidation phase. In group A, because of the acute shortening and static locking of the docking site, there was no need for compression. Otherwise, in group B, after docking was achieved radiologically, the docking site was compressed by 0.25 mm per day to provide full contact between the bone ends until the patient complained of pain at the docking site. Once docking was achieved in group B, in a second operative session, the transported segment was fixed to the dummy ring with Schanz pins and K-wires for additional stability.

In either group, after adequate lengthening of the femur was obtained, distraction was ceased. After consolidation, at least three cortices on the radiographs were obtained, the fixator was removed, and a protective brace was placed for a minimum of 4–6 weeks. During this period, partial weight bearing was allowed using two crutches or walker.

Test for normality of the variables was performed by the Shapiro-Wilk Test and histogram graphics. Data are given as a median (minimum, maximum) or numbers (percentage). The Fisher‘s exact test was performed to evaluate Paley’s bone and functional scores. The Mann-Whitney U test was used for statistical analysis to assess significant differences between groups in EFI, demographics, and number of complications per patient. The statistical software package SPSS 20.0 (IBM Corp, 2011, Armonk, New York) was used for analysis. Statistical significance was set at $p < 0.05$.

Results

The summary of the results of the study is presented in Tables 2 and 3. The mean EFI was lower in group A (mean: 31.8 days/cm; range: 24–50) than in group B (mean 48.7 days/cm; range: 40–100) ($p = 0.02$) (Table 4). The mean EFT was shorter in group A (mean: 120 days; range: 100–150) than in group B (mean: 290 days; range: 100–400) ($p = 0.0003$).

With respect to the bone and functional results, no difference was observed in Paley scores between the groups ($p = 0.96$ for bone and $p = 0.87$ for functional scores). In group A, bone scores were excellent in 11 patients, good in four, and fair in two. Functional scores were excellent in 10 patients, good in five, and fair in two. In group B, bone scores were excellent in 10 patients, good in three, and fair in two. Functional scores were excellent in nine patients, good in five, and fair in one.

Details of the complications (according to the classification system of Paley) encountered during the treatment period are summarized in Table 4. Deformity analysis was carried out based on the malalignment test and malorientation test, as described by Paley (Table 5) [14]. The number of complications per patient was approximately two times higher in group B than group A (2.2 ± 1.2 per patient in group B versus 1 per patient in group A, $p = 0.001$) (Table 6). According to the classification system of Paley, in group A, 12 problems were observed, including superficial pin-track infection (n: 9) that were treated by daily dressing and oral antibiotics in nine patients, transient knee flexion contracture (n: 2) in two, and angulation at the regenerate site (n: 1) in one. Four patients developed obstacles, which comprised delayed union at docking site (n: 1) in one patient and resulted in a grade-III pin-track infection (n: 3) in three. Delayed union was managed by autogenous bone grafting; grade-III pin-track infection led to premature pin removal. In addition, two patients suffered from sequelae (n: 2), which involved a knee flexion contracture of 10° treated by redressment under general anesthesia (n: 1) and a varus deformity of 15° (n: 1).

In group B, 21 problems were encountered, comprising superficial pin-track infection (n: 14) in 12 patients, a transient knee flexion contracture (n: 3) in three patients, angulation at the regenerate site (n: 2) in two patients, and delayed maturation of the regenerate site (n: 2) in two. Besides, seven patients experienced obstacles, which were a grade-III pin-track infection (n: 3) in three patients and delayed union (n: 4) at the docking site in four patients. Their management was similar to group A. Moreover, five patients from group B developed sequelae, which involved a valgus deformity of 15° (n: 1) in one patient, varus deformity of 10° (n: 2) in two patients, and a knee flexion contracture of 15° (n: 2) in two patients. While the patient with a flexion contracture received redressment under general anesthesia, others with sequelae denied the suggestion to correct their malalignment.

Table 5
Radiological evaluation of patients.

	Group A	Group B
Mechanic axis deviation (>10 mm)	1 patient	3 patients
Malorientation of the knee joint (>5°)	1 patient	2 patients

Table 6
Comparison of outcome parameters between the two groups (*Analyzed by Mann-Whitney U test.).

Variables	Acute shortening and re-lengthening group	Segmental bone transport group	P value
External fixator index(days/cm)	31.8 (range: 24 to 50)	48.7 (range: 40 to 100)	0.02
Number of complications per patient (mean)	1	2.2 ± 1.2	0.01

Discussion

One of the major drawbacks with the treatment of this bone transport technique is the long-lasting consolidation period, which requires about twice as long as the treatment period. This prolonged treatment period entails several disadvantages. First, such patients are at increased risk of the complications related to the use of an external fixator, including decreased range of motion in the adjacent joints and pin-track infections. Second, a long time in a frame can cause some psychiatric problems such as considerable patient discomfort and dissatisfaction. However, premature removal of the fixator due to the patient's intolerance of the prolonged treatment may lead to a fracture of the regenerated bone in the lack of any internal stabilization, which results in deformity, non-union, or shortening [10,11]. Therefore, in an attempt to reduce the EFT and the above stated complications, the acute shortening and lengthening technique and several combined methods, such as lengthening over a nail [11] and lengthening and then nailing [10], have been described over the past few decades. Either method employs the principles of Ilizarov's distraction osteogenesis and facilitates limb salvage and reconstruction. However, these methods also suffer from various limitations implied in the current literature and in our own clinical experience, including the risk of the infection extending along the length of the affected bone [8,9,11], knee stiffness [8], the need for acute deformity correction if present, and a demanding and multistep procedure [11].

With the intent to avoid or mitigate the aforementioned disadvantages, we developed and used a novel combined technique on the basis of the acute shortening and distraction osteogenesis in our clinical practice for more than 10 years. Actually, over the past decades, acute shortening after resection of the non-union zone, combined with lengthening of the shortened bone from another level using a circular external fixator, has been employed in the treatment of long bone non-unions with bone loss with favorable outcomes [4–7]. However, our technique is unique because, after acute shortening, we implanted a reamed retrograde femoral nail that is as short and large as possible and prefer using a monolateral external fixator to lengthen the femur, rather than the standard Ilizarov frame. With the use of such a retrograde nail, we aimed to increase the stability of the docking site and therefore decrease the EFI and prevent non-union or mal-union.

The primary outcomes of this study were to investigate the capability of our novel method to eradicate the infection as well as to illustrate whether this method could significantly reduce the EFI and related complication rate in comparison to the classic bone transport method. In a study which set out to compare EFT between bone transport and compression-distraction methods in the treatment of pseudarthrosis with bone loss, Saleh and Rees [6] observed that the distraction group demonstrated a shorter treatment time and a lower rate of complications. In their series, the total treatment time was 16 months and 9.8 months, respectively. They concluded that this large difference in terms of treatment time was secondary to delayed union at the docking site because the defect was closed gradually in bone transport. However, their study was heterogeneous in terms of the patient population and fixator type, including both femoral and tibial cases, in addition to unilateral and circular fixator use. Similar to Saleh and Rees, in a recent comparative study of these two treatment modalities, Eralp et al [7] found that the acute shortening and distraction technique is superior to the bone transport technique in terms of the EFI and complication rate, in the management of Cierny-Mader Type IV chronic tibial osteomyelitis with bone loss. In their study, the EFI was significantly lower in the acute shortening group (48.4 days/cm) than in the bone transport group (62.6 days/ cm), with a mean bone loss of 5.9 cm and 5.3 cm, respectively. In contrast, another recent investigation by Tetsworth et al [15] demonstrated no differences in terms of EFI between the two groups (the acute shortening group: 1.7 months/ cm; the bone transport group: 1.8 months/cm) in the management of infected tibial non-unions. The authors deduced that although either technique showed excellent bone and functional results, acute shortening and lengthening illustrated a lower rate of complication and a slightly better radiographic outcome.

The most important finding of the current study was that the mean EFI was significantly lower in the acute shortening group (the mean EFI: 31.8 days/cm; range 24–50) than in the bone transport group (the mean EFI: 48.7; range: 40–100). What's more, the novel combined technique group exhibited a lower complication rate than the bone transport group; the number of complications per patient was approximately two times higher in the bone transport group. In accordance with the previous literature reviewed above, our study confirmed that our modification of the acute shortening and re-lengthening technique could reduce the EFT and relevant complications compared with the bone transport technique in the treatment of the infected non-union of long bones. Furthermore, according to our review of the literature, most studies on this topic included patients with infected tibial non-unions with bone loss. Accordingly, there is limited experience in the literature regarding surgical management of infected non-union of the femur and limited data on the long-term survival of these patients [16]. The present study is one of the few clinical studies [6,9] to include a relatively large number of patients for investigating the long-term functional results of patients with chronic osteomyelitis of the femur.

It is also worth noting that patients with bone loss exceeding 10 cm are most often treated by bone transport, due to the limited capacity to tolerate acute shortening of this great amount. Otherwise, with a better understanding of the merits of immediate contact, those patients with bone loss less than 3 cm are generally managed using acute shortening and re-lengthening. Accordingly, the two techniques have not been adequately compared for the treatment of bone loss of intermediate size. Therefore, unlike most previous studies, we more specifically focused on infected non-union of the distal femur with size defects ranging between 3 cm and 10 cm [15].

Although four patients experienced delayed union at the docking site in the bone transport group, only one patient developed this frustrating complication in the acute shortening group. Moreover, while three patients from the bone transport group developed sequela, which included a valgus deformity of 15°, a varus deformity of 10°, and a knee flexion contracture of 10°, none of the patients from the novel technique group suffered from sequelae. We realized that these findings were similar to the results of previous bone transport studies [4,12,17–19]. Moreover, these results may be interpreted as evidence that the retrograde nail can confer sufficient stability of the docking site and thus shorten the EFI and prevent non-union and mal-union.

In terms of the Paley functional and bone scoring system, no difference was observed between the two techniques. These findings may be interpreted as an argument that our combined technique, based on acute shortening and re-lengthening, can be performed for the treatment of Cierny-Mader Type IV osteomyelitis of the distal femur as safely and effectively as the bone segment transport for which the technical feasibility, safety, and clinical benefit are well confirmed [3]. Conversely, acute shortening exceeding 7 cm and re-lengthening from a different region of the involved bone can adversely influence muscle function. In our study, although no difference was found in terms of functional scores between the groups, it should be kept in mind that shortening from the tendinous part and lengthening from the sarcomere region of the muscle can deteriorate the function of the extremity, especially for defects more than 7 cm [7]. Therefore, satisfactory functional results may be expected for select patients who receive acute shortening of approximately 7 cm.

As mentioned previously, another alternative method for managing patients with segmental bone defects due to debridement of osteomyelitis is the combined technique of bone segment transport over an intramedullary nail using an external fixator (lengthening over a nail) [9]. Indeed, this technique is a well-established procedure for femoral lengthening [8]; however, the use of this procedure in the management of infected non-union of long bones is a new concept. According to this technique, an intramedullary nail is placed concurrently with the external fixator. At the end of the distraction stage, the nail is locked with two distal screws, and then the fixator is removed. Accordingly, the nail preserves the newly formed bone from fractures during the consolidation phase and allows it to maintain length and alignment during the lengthening, neutralizing the forces on the femur [9,11]. However, this established technique is rarely performed in the management of osteomyelitis due to the potential risk of the infection associated with the retained hardware [9]. Pin-track infections are unavoidable when using an external fixator [17] and can be the cause of deep infections spreading to the intramedullary nail [8]. Kocaoğlu et al [9] reported two recurrences of the deep infection in their case series of 13 patients with chronic osteomyelitis, which resolved by removing nails [9]. Conversely, although three patients who received our technique developed a grade-III pin-track infection, we did not experience any premature removal of the external fixator due to recurrence of a deep infection in our case series.

We consider that the strategy described by Cierny et al [1,20,21] is essential to avoid such a rare, but dangerous, complication. Accordingly, we believe that the lower rate of infection in the novel technique group was based on the shorter EFI and our thorough surgical technique, which was comprised of meticulous radical debridement and removal of all necrotic and infected tissue, in addition to the placement of Schanz screws with a clear space left between the nail and screws. Additionally, as far as we are concerned, the use of a nail that is as short as possible may help to prevent a possible deep infection. We infer that in the event of such a complication, our strategy can prevent the spread of the infection along the proximal part of the femur, and the infection would affect only a limited portion of the distal femur. Also, there is, of course, no doubt that the administration of appropriate antibiotic therapy is one of the mainstays in the treatment of chronic osteomyelitis.

Finally, several limitations need to be considered. First, this study was conducted retrospectively in a small number of patients, and this limits the power of the results. Second, bone transport was applied earlier in this series by different surgeons, but the novel combined technique was performed by only one surgeon after he had already become experienced with the Ilizarov technique. Thus, results in selection bias may cause differences in complication rates between the two techniques. Nevertheless, we describe a novel and successful alternative technique for the management of a select group of patients with this rare and challenging condition.

Conclusion

Although both techniques can provide satisfactory functional and bone results, the novel combined technique of acute shortening and lengthening and a monolateral external fixator can confer a shorter treatment period with a lower rate of complications. Furthermore, this novel combined technique may increase the stability of the docking site at the distal femur and therefore prevent non-union and mal-union, as well as enhancing the activity and comfort level of the patient. All in all, this study showed that acute shortening and re-lengthening is an appropriate technique for the infected non-union of the distal femur with size defects ranging between 3 cm and 10 cm. Therefore, we recommend using our technique for select patients, who exhibit infected non-union of the distal femur with a bone loss of up to 10 cm.

Declaration of Competing Interest

The authors “Cengiz SEN, Mehmet Demirel, Yavuz SAGLAM, Halil I. BALCI, Levent ERALP, Mehmet KOCAOGLU” individually declare that they have no conflict of interest, and no benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References

[1] Cierny Iii G, Mader JT, Penninck JJ. The classic: a clinical staging system for adult osteomyelitis. Clin Orthop Relat Res 2003;414:7–24.
[2] Papakostidis C, Bhandari M, Giannoudis P. Distraction osteogenesis in the treatment of long bone defects of the lower limbs: effectiveness, complications and clinical results; a systematic review and meta-analysis. Bone Joint J 2013;95:1673–80.
[3] Ilizarov GA. The tension-stress effect on the genesis and growth of tissues. Part I. The influence of stability of fixation and soft-tissue preservation. Clin Orthop Relat Res 1989;238:249–81.
[4] Sen C, Eralp L, Gunes T, Erdem M, Ozden VE, Kocaoglu M. An alternative method for the treatment of nonunion of the tibia with bone loss. J Bone Joint Surg Br 2006;88:783–9.
[5] Giebel G. Resection debridement of the lower leg with compensatory callus distraction. Der Unfallchirurg 1991;94:401–8.
[6] Saleh M, Rees A. Bifocal surgery for deformity and bone loss after lower-limb fractures. Comparison of bone-transport and compression-distraction methods. J Bone Joint Surg Br 1995;77:429–34.
[7] Eralp L, Balci HI, Kocaoglu M, Sen C, Celiktas M, Tomak Y, et al. Is acute compression and distraction superior to segmental bone transport techniques in chronic tibial osteomyelitis? Comparison of distraction osteogenesis techniques. Acta Orthop Belg 2016;82:599–609.
[8] Song HR, Oh CW, Mattoo R, Park BC, Kim SJ, Park IH, et al. Femoral lengthening over an intramedullary nail using the external fixator: risk of infection and knee problems in 22 patients with a follow-up of 2 years or more. Acta Orthop 2005;76:245–52.
[9] Kocaoglu M, Eralp L, Rashid HU, Sen C, Bilsel K. Reconstruction of segmental bone defects due to chronic osteomyelitis with use of an external fixator and an intramedullary nail. JBJS 2006;88:2137–45.
[10] Rozbruch SR, Kleinman D, Fragomen AT, Ilizarov S. Limb lengthening and then insertion of an intramedullary nail: a case-matched comparison. Clin Orthop Relat Res 2008;466:2923–32.
[11] Paley D, Herzenberg JE, Paremain G, Bhave A. Femoral lengthening over an intramedullary nail: a matched-case comparison with Ilizarov femoral lengthening. JBJS 1997;79:1464–80.
[12] Paley D, Catagni MA, Argnani F, Villa A, Bijnedetti GB, Cattaneo R. Ilizarov treatment of tibial nonunions with bone loss. Clin Orthop Relat Res 1989;241:146–65.
[13] Paley D. Problems, obstacles, and complications of limb lengthening by the Ilizarov technique. Clin Orthop Relat Res 1990;250:81–104.
[14] Paley D, Herzenberg J. Principles of deformity correction. Berlin: GermanySpringer-Verlag; 2002.
[15] Tetsworth K, Paley D, Sen C, Jaffe M, Maar DC, Glatt V, et al. Bone transport versus acute shortening for the management of infected tibial non-unions with bone defects. Injury 2017;48:2276–84.
[16] Yin P, Ji Q, Li T, Li J, Li Z, Liu J, et al. A systematic review and meta-analysis of Ilizarov methods in the treatment of infected nonunion of tibia and femur. PLoS One 2015;10:141–973.

[17] Garcia-Cimbrelo E, Olsen B, Ruiz-Yagüe M, Fernandez-Baillo N, Munuera-Martinez L. Ilizarov technique. Results and difficulties. Clin Orthop Relat Res 1992;283:116–23.
[18] Atesalp AS, Basbozkurt M, Erler K, Sehirlionğlu A, Tunay S, Solakoğlu C, et al. Treatment of tibial bone defects with the Ilizarov circular external fixator in high-velocity gunshot wounds. Int Orthop 1998;22:343–7.
[19] Song HR, Cho SH, Koo KH, Jeong ST, Park YJ, Ko JH. Tibial bone defects treated by internal bone transport using the Ilizarov method. Int Orthop 1998;22:293–7.
[20] Cierny III G. Infected tibial nonunions (1981-1995): the evolution of change. Clin Orthop Relat Res 1999;360:97–105.
[21] Tetsworth K, Cierny III G. Osteomyelitis debridement techniques. Clin Orthop Relat Res 1999;360:87–96.