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ORTHOPAEDIC SURGERY

Bilateral tibial lengthening over the nail: our experience of 143 cases

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Abstract
Introduction Using lengthening over an intramedullary nail as a technique for cosmetic purposes improves the individuals' quality of life and provides more satisfactory results due to less external fixator period.
Methods This study reports a case series of 143 individuals who underwent bilateral tibial lengthening over an intramedullary nail for cosmetic purposes together with the review of parameters related to the surgery and complications. Level of satisfaction was measured with the standard visual analog scale at least 1 year after removal of external fixator.
Results In this study, mean (SD) age of patients was 26.6 (7.26) years. 85 (59.4 %) participants were male and 58 (40.6 %) were female. Mean end lengthening of all individuals was 6.65 cm. The mean external fixator period was 93.7 days. Complication rate was 0.74 per segment but it decreased to 0.45 when pin-tract infection was excluded. Complications were categorized based on Paley et al.'s classification as 129 problems, 85 obstacles and no sequelae. Interestingly, 44 (30.8 %) individuals had no problem and obstacle.
Conclusions Lengthening over an intramedullary nail provides bone formation in equal quality to that obtained by the conventional Ilizarov method, along with lower rate of complications. The large number of individuals involved in our study is a remarkable benefit which could be used as an appropriate sample to compare results for outcomes and complications.

Keywords Lengthening over the nail · Tibia · Lengthening

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Introduction

Leg lengthening was first described by Codivilla in 1905; since then it has been widely used for different purposes [1]. The lengthening procedure consists of two phases: the distraction phase, and the consolidation phase. During the distraction phase, application of an external fixator is required. Initially, an osteotomy is performed, followed by gradual distraction until the desired length has been achieved. The consolidation phase takes almost twice as long as the distraction phase [2, 3]. This technique is associated with many complications such as pin-tract infection, osteomyelitis, equinus deformity, joint stiffness, inappropriate bone formation, muscle contractures, pain, interference in usual daily activities, and risk of bone fracture after removal of the external fixator [4–9].

In 1997, Paley introduced bone lengthening over an intramedullary nail. This technique reduces the external fixation period. This reduction minimizes the possibility of infection [6, 10]. It also prevents joint stiffness as it enables

the patient to achieve a rapid return to normal range of motion and to exercise joints. Furthermore, axial alignment is secured through this procedure, length gained is maintained, and it prevents refracture after the removal of external fixator [11–14].

Another method of lengthening is using implantable intramedullary nail that was first designed in 1977 by Jäger [15] in which distraction is conducted electronically with motor located at the end. Baumgart et al. and Krieg et al. [13, 16] also described the results of using the mentioned method on patients with limb length discrepancies. Its advantages consisted of minimal scaring, preventing the risk of joint stiffness, lacking of pin sites, providing comfort, and reducing infection and pain. But the method is more costly than the other external ones. Also additional operation may be needed and technical problems such as breaking the wire and failure of motor may occur. Muscle weakness is probable due to not weight bearing as well.

In comparison with different lengthening techniques, lengthening over an intramedullary nail provides a more comfortable process in which better bone formation is seen [10]. This technique improves the individuals' quality of life and provides more satisfactory results [12, 14]. However, it carries a risk of fat embolism, a higher risk of blood loss, disturbance of intramedullary circulation and increased possibility of pin-tract infections, which may lead to deep intramedullary infections [11].

This study reports a case series of 143 individuals who underwent bilateral tibial lengthening over an intramedullary nail together with the review of parameters related to the surgery and complications.

Materials and methods

In this case series, the data related to 143 individuals who underwent tibial lengthening over nails in Sina Shemiran surgical center for cosmetic purposes between 2001 and 2010 are reported.

Individuals who were referred for leg lengthening for cosmetic purposes were notified about the complete procedure, the possible complications as well as the duration of the process. Informed consent was obtained from the patients. Anterior posterior and lateral radiography of both legs were taken to determine the calf length and the appropriate nail characteristics.

Operation procedure

At operation, reaming of the intramedullary canal over an intramedullary nail (of the diameter of 8–11 mm based on patient's size) was performed to attain a diameter of 0.5–1 mm larger than the diameter of the selected nail. Nail length was dependent on the individuals' height, so that maximum possible size of nail was selected regarding the individuals' length of tibia. After tibial and fibular osteotomy through an incision of 1 cm, the intramedullary nail was inserted to the reamed canal. This was followed by the proximal and distal pins that were fixed on external rings by slotted screw. In this method, the first pin was passed through the proximal head of fibula and tibia as well as the second pin to fix the distal heads of the bones. Afterwards, the second ring on the distal side was fixed (Fig. 1). Number of pin changed based on the learning curve. In primary years, a total number of four pins were applied, two proximal and two distal, which increased to ten pins, six proximal and four distal. The procedure took approximately 4.5 h. The conditions of the subjects were assessed during the first visit. The lengthening process was initiated after 5–7 days at a rate of 2 mm/day at the first week followed by 0.25 mm every 6 h later. Simultaneously, the physical therapy was started to stretch and empower hip abductors, quadriceps femoris, calf muscles and Achilles

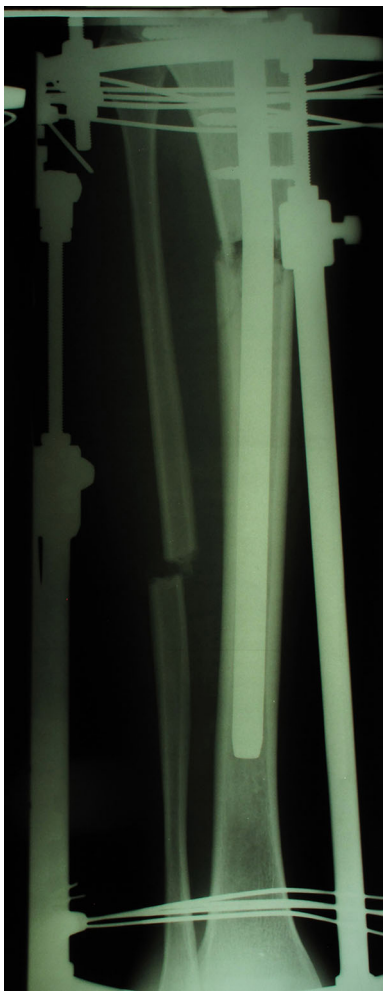

Fig. 1 External fixator and insertion of pins, anterior posterior view

Fig. 2 After removal of external fixator, anterior posterior view

Fig. 3 Regenerated bone, anterior posterior view

tendon. In case of severe shortness of Achilles and in the individuals with weak cooperation for regular physical therapy and routine exercises, Achilles tendon lengthening (ATL) was performed base on the physician's decision.

The bone regeneration was usually assessed every 2 weeks by taking X-ray images and different clinical parameters were checked and recorded. The rate of lengthening was adjusted to ensure that rapid bone formation was not accompanied by premature union. The subjects were carefully investigated (even through the home visits) in order not to miss any possible complications. Once the desired length was achieved, two screws were inserted into the medullary nail at the distal side of the bone, and the external fixator was removed (Fig. 2). The intramedullary nail supported the bone during the consolidation phase and allowed the removal of external fixator after the distraction phase of lengthening. Most of the individuals were followed up for at least 6 months so that their range of motion, level of pain and regenerated bone quality could be evaluated (Fig. 3).

For better results, the subjects were fully notified about the importance of hygiene and physical therapy before and after the procedure. Three sessions of 1.5 h of physical therapy were carried out during a week for external fixation period, and the intensity and intervals of the exercise were adjusted after the lengthening of above 3 cm. Meanwhile after removal of external fixator, the physical therapy was continued until equinus deformity recovered. In all cases, Cefazolin (1 g/TDS) was administered along with Cloxacillin (1.5–2 g daily) during hospitalization. Then 7–10 days oral antibiotic was also prescribed. During the lengthening, in case of clinical diagnosis of infection (including pin-tract infection, deep intramedullary infection, osteomyelitis), appropriate antibiotic was administered. NSAIDs were prescribed for pain management as needed. Nutritional consultations were also provided. After the whole procedure was carried out and the desired length was achieved, the intramedullary nail was statically locked. Meanwhile, level of satisfaction was measured with the standard visual analog scale (VAS) at least 1 year after

removal of external fixator. VAS consists of a 10-cm horizontal line showing no satisfaction at the left and highest level of satisfaction at the right.

Statistical methods

Descriptive statistics was used to report characteristics of subjects. Mean and standard deviation (SD) were reported for continuous variables, as well as number and percentage for categorical data.

Comparison of leg lengthening and mean external fixator period in different groups of dichotomous variables (i.e., gender in this study) was performed using independent samples *t* test. The cutoff point for the comparison of lengthening amount and occurrence of complications was calculated using ROC curve.

Results

This study included 143 patients who underwent bilateral tibial lengthening over an intramedullary nail. Mean (SD) age of patients was 26.6 (7.26) years, with a mean height and weight of 157.8 cm and 60.3 kg, respectively. 85 (59.4 %) participants were male and 58 (40.6 %) were female. Table 1 demonstrates demographic characteristics of the cases in both genders. 82.5 % of the individuals were married and 16.8 % were single. 124 (86.7 %) subjects were right-handed. Mean end lengthening of all individuals in this study was 6.65 cm (3.5–13); 6.38 cm in men and 7.08 cm in women (Table 2). The difference in leg lengthening between the both genders was statistically significant ($P < 0.001$). The mean external fixator period was 93.7 days; 86.6 days in males and 103.9 in females which was significantly different ($P < 0.001$). The mean External Fixation Index was 14.11 day/cm (Table 2). We found a significant negative correlation between end lengthening and cases' height ($P < 0.001$, Pearson correlation $= -0.490$). The subjects were followed up for a mean duration of 14 months. The minimum time of follow-up was 41 days, and the maximum was 75 months. 80 % of individuals could bear weight 1 day after the surgery and 65 % of them could take a first step on the same day. The lengthening began 5.6 days after the surgery. 126 (88.1 %) subjects were hospitalized less than 2 days after the surgery. Mean (SD) level of satisfaction was 8.7 (2.2).

One hundred and two individuals suffered from equinus deformity at least once during the lengthening. Among these 22 (15.3 %) needed Achilles tendon lengthening (ATL). Out of these 22 subjects, 15 underwent bilateral ATL and 7 unilateral ATL. Other cases of equinus deformity were managed by physical therapy. Nonunion occurred in three individuals (2.1 %) which was bilateral in these subjects. Union was achieved after bone transport in two of these individuals. The third case underwent autograft transplantation from iliac crest followed by allograft transplantation due to the unsuccessful response.

Table 1 Demographic characteristics of cases

Variable	Mean	SD
Height (cm)	157.89	9.54
Male	163.39	7.13
Female	149.64	6.13
Weight (kg)	60.27	11.72
Male	65.92	9.87
Female	51.45	8.54
Age (year)	26.64	7.23
Male	27.81	7.38
Female	24.87	6.69

Table 2 End lengthening (cm) and External Fixation Index (day/cm)

Variable	Minimum	Maximum	Mean	SD
End lengthening (cm)	3.5	13.0	6.65	1.33
Male	3.5	13.0	6.38	1.40
Female	4.0	9.5	7.08	1.14
External Fixation Index (Day/cm)	7.43	28.00	14.11	3.14
Male	7.43	19.88	13.65	2.70
Female	8.46	28.00	14.84	3.67

For premature union, osteoclasis (acute lengthening) was performed in seven subjects (6 in tibia and 1 in fibula).

During the lengthening, internal and external rotation of the foot occurred in 38 (26.7 %) and 7 individuals (4.9 %), respectively, and all of them were corrected.

Tibial fracture occurred in five (3.5 %) subjects and all of whom recovered with no surgical intervention. Three tibias fractured during the surgery. Car accident (crash injury) was another reason for fracture of the tibia in one patient. In another patient distal tibial fracture occurred during the lengthening.

No osteomyelitis occurred in our study. However, pin-tract infection was seen in 65 (45.7 %) individuals, all of whom responded to oral antibiotics. We had no pin-tract infection stage IV. Table 3 summarizes all the problems and obstacles that occurred for the cases based on Paley's classification, as evident there were no sequelae in this case series [4]. Our complication rate was 0.74 per segment but it decreased to 0.45 when pin-tract infection was excluded. Interestingly, 44 (30.9 %) individuals had no problem and obstacle. Among seven documented items shown in Table 3, the maximum of four items were seen simultaneously in subjects who encountered with these problems and obstacles.

Table 3 Problems, obstacles and sequelae

Complication type	Case	Segment	Complication type	Solution
Pin-tract infection	65 (45.7 %)	84	Obstacle	Oral antibiotics
Pin fracture	39 (27.4 %)	55	Problem	Pin replacement or pin removal
Equinus deformity	22 (15.4 %)	37	Problem	Subcutaneous Achilles tendon lengthening
Non union	3 (2.1 %)	5	Problem	Bone transfer/auto graft transplantation
Premature consolidation	7 (4.9 %)	7	Problem	Osteoclasis (acute lengthening)
Nail breakage	16 (11.3 %)	19	Problem	Nail replacement
Tibial fracture	5 (3.5 %)	5	Problem	Conservative therapy
Compartment syndrome	1 (0.7 %)	1	Problem	Fasciotomy

Based on ROC curve we found that cutoff point of 6.25 cm for the lengthening amount (sensitivity 68, specificity 57) is a level above which the number of complications arises. A lengthening amount of less than 6.25 cm was significantly safer for complication occurrence than longer lengthening (Chi-square test, $P = 0.04$). We also found a significant positive correlation between total complication and end lengthening amount ($P < 0.001$).

Discussion

In this series, 143 individuals over a time period of 9 years were reported who underwent bilateral lengthening over an intramedullary nail for cosmetic purposes. Catagni et al. [17] reported experience of 54 cases, and they applied Ilizarov method for lengthening. Kocaoglu et al. [1] described 35 subjects. Kim et al. [14] reported 13 individuals for whom Ilizarov external fixator and a nail in combination were applied. In Simpson et al.'s [18] study, 20 cases of subjects with leg lengthening over an intramedullary nail were presented. Baumgart et al. and Krieg et al. [13, 16] described the results of using fully implantable intramedullary nail in 12 and 32 patients with limb length discrepancies, respectively. In this study, mean end lengthening was 6.65 cm. Catagni et al. [17] reported a mean end lengthening of 7 cm (Ilizarov technique) and in Kocaoglu et al.'s [1] study it was 6.3 cm. In a study done by Kim et al. [14] the mean lengthening was 4.19 cm. Simpson et al. [18] reported a mean leg lengthening of 4.7 cm. Also in Baumgart et al's study [13] patients' leg length discrepancies (3–7.5 cm) were fully corrected. In this study, mean external fixator period was 93.7 days, which was over a 9 month and 17 days in Catagni et al.'s [17] report and 17.8 days per cm in Chaudhary's study [19]. The smaller external fixator period helped to minimize the incidence of the problems [2, 4]. The mean External Fixation Index was 14.11 day/cm, which was 18.7 days/cm in Kocaoglu et al.'s study. In Kim et al.'s study [14] the mean duration of external fixation was 12.58 days per centimeter gain in length. In Simpson et al.'s study [18] the mean time for external fixation was 98 days. Table 4 compares the average length achieved (cm) and external fixation time or distraction index (day/cm) in various studies. Similar to Kim et al.'s study authors believe that if the External Fixation Index lessens, the individuals will be more capable of starting physical therapy on the ankle joints and therefore, avoiding irreversible joint contracture [14]. The modified 5/8 rings were applied as proximal rings to prevent knee joint contracture, reduce patient discomfort and provide the better condition to follow the physical therapy. Using these modified rings, as compared to complete rings used in classic Ilizarov method, did not limit knee flexion and let the subjects do full knee flexion during lengthening. Hence knee range of motion was not limited. In post-operative visits it was observed that the ankle joint range of motion recovered to the preoperative one. Similar experiences were also demonstrated by Kim et al. [14].

In the current study, patients showed high levels of satisfaction in at least 1 year after the removal of external fixator. The same result was also reported in Park et al.'s study [10].

In this study, the subjects were followed up for a mean duration of 14 months. The mean follow-up was 6.25 years in Catagni et al.'s research [17]. Baumgart et al. [13] followed the patients for at least 2 years. Median follow-up period was 16 months for Krieg et al.'s [16] study. We found the critical cutoff point of 6.25 cm in this case series above which the complications arise while in Kocaoglu et al.'s study, the cutoff point was 6 cm. The most common complication was pin-tract infection while Kim et al.'s reported equinus contracture and valgus angulations of tibia as their most common complications [20]. Our findings showed lower overall complication rate (0.74 per segment) than Paley's study (1.4) but it was higher in

Table 4 Comparison of average end lengthening and external fixation index in different studies

References	Number of cases	Bone	Method of lengthening	Average length achieved (cm)	External Fixation Index/Distraction Index (day/cm)
The present study	143	Tibia	LON	6.65	14.11
Catagni et al. [17]	54	Tibia	Ilizarov	7	Almost 40
Kocaoglu et al. [1]	35	Femur and Tibia	LON	6.3	18.7
Kim et al. [14]	13	Tibia	LON	4.19	12.58
Simpson et al. [18]	20	Femur and Tibia	LON	4.7	20
Kim et al. [20]	40	Tibia	LON	7.73	33
Chen et al. [8]	21	Tibia	LON	4.23	13.85
Guo et al. [9]	13	Tibia	Ilizarov	7.2	40.0
Guo et al. [9]	26	Tibia	LON	7.4	17.4
Baumgart et al. [13]	12	Femur	Implantable motorized intramedullary nail	4.5	12.4

comparison with Kocaoglu et al.'s work (0.43). The rate of complication decreased to 0.45 when pin-tract infection was excluded, but this rate was 0.9 in Paley et al.'s study and 0.3 in Kocaoglu et al.'s study. Equinus deformity which needed ATL occurred in 22 individuals (15.4 %). In Catagni et al.'s [17] study this was seen in 19 subjects (35.5 %). Krieg et al. [16] reported one case of persisting equinus deformity of the foot which was resolved by osteotomy of talus and calcaneus. In this study, nonunion was demonstrated in three individuals (2.1 %). We believe that the reason for nonunion was lost to follow-up in the first patient, hypothyroidism in the second and excessive alcohol usage in the last patient. We believe that before the procedure and during the lengthening, these issues should be considered. Bone transport was performed in two and autograft transplantation from iliac crest followed by allograft transplantation was performed in the third case to achieve union. In Kocaoglu et al.'s [1] study delayed union was observed twice, and they applied autologous cancellous bone grafting for achieving union. Oh et al.'s study [21] has also shown the advantages of bone transport in patients who underwent bone transport over an intramedullary nail for tibial reconstruction. Seven subjects developed premature union who were undergone osteoclasis (acute lengthening) (6 in tibia and 1 in fibula). All seven were treated with this intervention. The case of premature fibular consolidation was as a result of insufficiency of fibular osteotomy. For tibial premature consolidation, it was assumed that the amount of increase in the frame did not similarly transfer to the osteotomy site thus the lengthening rate was increased to 2 mm/day at the first week of the process. In this study, foot internal rotation occurred in 26.6 % and external rotation in 4.9 % during the lengthening, and all of them were corrected. The principle disadvantage of lengthening over an intramedullary nail is the increased risk of intramedullary infection following the combined use of external and internal instruments.

In Kim et al.'s [22] study, 13 out of the 118 segments developed superficial infection and 6 segments showed deep infection. In this series only one compartment syndrome occurred as the result of osteotomy site hemorrhage, which led to fasciotomy. Pin-tract infection was seen in 65 (45.7 %) individuals in this study and similarly Catagni et al.'s report [17], all responded to oral antibiotics. No case of deep infection was demonstrated in this study, which is more satisfactory as compared with the previous study reports (2.4 % by Kocaoglu et al. [1], 3 % by Paley et al. [12], 5 % by Silberg et al. [23], 15 % by Simpson et al. [18]). Paley et al. reported one case of deep infection in their 29 subjects. They recommended that the contact between the nail, and the Schanz pins of the external fixator should be prevented and interlocking screws should be placed medially rather than laterally. Furthermore, in Kocaoglu et al.'s study deep infection occurred in only one of the 42 segments [1]. We believe that the absence of deep infection in our report is the result of applying Ilizarov pin but as mentioned above Paley et al. used Schanz pins which may increase the risk of deep infection. Moreover, using more pins, we would be able to remove the infected pins at first stages of pin-tract infection and prevent the progression to deep infection. During the years and by observing the cases, we found that there was the possibility of pin breakage due to weight bearing during the lengthening, so we understood that by increasing the number of pins, we have the chance to remove the broken pins and we do not need to replace it. At the beginning, because of lower number of pins, once a pin was broken or in case of pin-tract infection, the individuals were taken to the operating room and pin replacement was performed. Also, we found that increasing pins allows us to remove any of them in case of pin-tract infection, and the rest of them can remain at the site.

Previous studies have reported nail-induced complications, including deep infection, nail or interlocking screws breakage and protrusion of nail [5, 11]. When the nail diameter is less than 8 mm, these complications usually occur, especially when a 6.7 mm unreamed humeral nail is used in the tibia. In these circumstances, the nail is not able to bear the body weight after the removal of external fixator, and it breaks [14]. We used nails of 8–11 mm diameter, and reaming of the intramedullary canal over an intramedullary nail was performed to get a diameter of 0.5–1 mm larger than the diameter of the selected nail. During this 9 years, 16 cases experienced nail breakages. As far as we have used different nails for the individuals, and these breakages occurred in the same period of time, we believe that the result of this problem is due to the nature of the nail used not the technique of lengthening over an intramedullary nail itself and the procedure of reaming.

Conclusion

Lengthening over an intramedullary nail provides bone formation in equal quality to that obtained by the conventional Ilizarov method of lengthening. In addition, it provides a lower rate of complications and more comfort for the clients due to the reduced external fixation period [11]. The large number of individuals involved in our study is a remarkable benefit which could be used as an appropriate sample to compare results for outcomes and complications.

Conflict of interest None.

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