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Research Article

Femoral Bone Elongation through External Fixation. Comparative Study between the Traditional Technique and the Technique Assisted by an Intramedullary Nail

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Abstract

The use of external fixation is the most common technique for bone elongation. While this technique is very versatile, its use is not free of difficulties, and some surgeons have used it to perform elongations over an intramedullary nail to minimize the time the patient has the fixator implanted.

Theoretically, the reduction of the external fixation time would imply fewer problems of infection of the screws, more comfort for the patient, and less joint stiffness. In addition, having an internal support would reduce angular deviations and decrease the fracture rate of the regenerated bone.

To compare the two techniques, two groups of 15 femurs (N=30), homogeneous in terms of age, the amount of elongation, the elongation difficulty (according to Paley's criteria), and the etiology of the shortening, were paired. From these groups, the external fixation time, external fixation rate (fixation time per centimeter of elongation), consolidation index (months per centimeter of elongation), complication rate (classified according to Paley's criteria), and range of motion of the knee were analyzed.

After analyzing the data, statistically significant differences were found in favor of elongation over a nail in the external fixation time, in the external fixation index, in the rate of complications, and in the range of articular motion. No differences were found in the bone consolidation index or the clinical results obtained.

ABBREVIATIONS

LON: Lengthening Over a Nail; EFL: External Fixation Lengthening

INTRODUCTION

Callotasis is the most commonly used elongation procedure. It has been used in the correction of skeletal deformities since the dissemination of the work of authors such as Ilizarov, and its popularization in the West is thanks to works such as those performed by De Bastiani and the School of Verona [1-3]. The most common method for performing the elongations is one that uses an external fixator to set the bone during the distraction, neutralization, and dynamization phases. The device remains in position throughout the process and is removed once the regenerated bone is able to support the weight of the patient's body in his/her daily activities.

External fixators are minimally invasive, allow corrections in multiple planes, and permit controlling the rigidity of the assembly at the will of the surgeon. However, their use is not without problems and presents a number of limitations, including the following:

- Need for patient collaboration (care of the fixator and hygiene);
- Psychological acceptance of the external support;
- Risk of infection;

- Joint stiffness or muscular contractures due to transfixion of the soft tissues;
- Mounting apparatus and difficulties in the patient's daily life; and
- Deciding the time of removal without the risk of suffering a fracture of the regenerated bone.

Although several intramedullary elongation devices have appeared in recent years to avoid the drawbacks of external fixation, their use has not yet become popular for a number of reasons:

- Little clinical experience (and the existing device has not always been as good as would be desirable);
- Cannot be used in patients with significant bone deformities;
- Not suitable for patients of very small size or with narrow medullary canals;
- Inability to perform minor corrections;
- The distraction mechanisms are fragile and, if damaged, the result is a complete failure of the treatment; and
- High cost of the implants.

As an intermediate solution, some authors have used the technique known as lengthening over a nail (LON), a procedure that involves implanting an intramedullary nail and an external fixator at the same time during surgery. The nail is only blocked at one of its ends and acts as an external support for the elongation, which is performed thanks to the distraction of the fixator. Once the desired length is reached, the patient is taken to the operating room, and the other end of the nail is blocked, removing the fixator in the same act. The theoretical advantages of this technique are multiple:

- Lower risk of infection of the tract of the screws;
- The patient suffers the discomfort of the fixator itself for less time;
- The external support helps to reduce axial deviations during the elongation;
- The intramedullary nail minimizes the risk of fracture of the regenerated bone; and
- Less time of muscle transfixion and, therefore, lower risk of stiffness or contracture.

However, the LON technique may also present an increased risk of deep infection (due to endomedullary implantation) and involves more aggressive surgery than the standard technique with the use of an external fixator alone. Upon analyzing the existing literature, we identified several studies that have found significant differences between the use of the LON technique and the traditional technique (without the assistance of a nail) [4-8].

To analyze the results of both techniques, the findings collected for each of them were systematically analyzed and compared in a National Reference Unit for Infantile Orthopedics. The hypothesis to be demonstrated is that the bone elongations assisted by LON are more effective than can be achieved with an isolated external fixation (External Fixator Lengthening or EFL) for the accomplishment of femoral elongation.

MATERIALS AND METHODS

To compare both techniques (EFL versus LON), we retrospectively analyzed two groups of fifteen elongations with each method. For both groups to be comparable, after their anonymization, the different patients were matched according to four criteria: amount of elongation, age, etiology (congenital, post-traumatic, or acquired), and difficulty (mild, moderate, and severe). To assess the difficulty, the criteria published by Paley [4] (Table 1), which are commonly accepted, were utilized. From there, the different patients were paired if there were three or more agreements in these four analyzed parameters. Thus, eight of the patients were comparable in all four criteria and seven in three of the criteria (Table 2).

Femoral elongations assisted by an intramedullary nail (LON)

Fifteen femoral bone elongations performed on fourteen patients operated upon between February 2003 and December 2013 are included in this study. The mean follow-up time was 2.5 years (range 2–10 years). The mean age of the patients at the time of surgery was 20.67 years (range 16–30 years). Twelve patients were men, and three were women. Thirteen patients were treated for discrepancy in the length of one limb, and one patient was lengthened bilaterally because of his/her small size. The nails were inserted anterograde in thirteen of the cases (with subtrochanteric osteotomy) and retrograde in the remaining two (supracondylar osteotomy). The difficulty level was classified according to Paley's scale: five severe, seven moderate, and three mild cases were counted. Simultaneous elongations were not performed in the femur and ipsilateral tibia.

Femoral elongations by isolated external fixation (EFL)

These patients were selected from a much larger group (twenty-five cases) operated upon between May 2002 and December 2013. The patients were anonymized and classified according to the same four parameters used for the LON group. The cases were then matched so that the fifteen selected cases were as homogeneous as possible.

The mean duration of follow-up was 3.5 years (range 2–10 years). The mean age of the patients at the time of surgery was 18.87 years (range 12–37 years). Ten patients were male, and five were female. All elongations were performed for dissymmetry of one limb. The osteotomies were subtrochanteric in four femurs (26.66%), mediodiaphyseal in one femur (6.66%), and distal-third in ten femurs (67.66%).

The level of difficulty (according to Paley) was rated as severe in seven cases, moderate in five, and mild in three. In ten cases, angular or rotational corrections had to be made in the same elongation osteotomy. In one case, ipsilateral tibial elongation was performed simultaneously.

Variables studied to compare LON and EFL

To analyze the differences between the clinical results obtained using the two methods, we evaluated a series of

Table 1: Classification of elongation difficulty (Paley et al. 1997).

	0 points	1 point	2 points	3 points
Age (years)	5–19	0–4 and 20–29	30–50	> 50
Complexity of correcting the deformity at the elongation level	None	Angulation > 5°, < 20° Rotation > 10°, < 30° Translation < 50% of the bone diameter Displacement of the mechanical axis of 1–3 cm	Angulation > 20° Rotation > 30° Translation > 50% of the bone diameter Displacement of the mechanical axis >3 cm	Combination of deformities at 1 level Multiple deformities
Other levels of treatment in the same bone	None	1 additional level, medium complexity	1 additional level, moderate complexity	1 additional level, severe complexity, or > 2 levels
Associated with tibial enlargement (cm)	None	1–3	3,1–6	> 6
Joint instability	None	Grade I – medium instability: anteroposterior knee instability +/+++ hip: no break of Shenton's arch	Grade II – moderate instability: anteroposterior knee instability ++/+++ hip: reducible break of Shenton's arch	Grade III – fixed subluxation or fixed luxation
Fixed deformity in knee flexion (degrees)	0	1–5	6–20	> 20
Knee flexion	> 120°	100–120	65–99	< 65
Articular osteoarthrosis	None	Marginal osteophytes Subchondral sclerosis	Narrowing of the articular space	Loss of the articular space
Bone quality	Normal	Ollier disease Osteoporosis Pseudoarthrosis	Radiation Neurofibromatosis Imperfect osteogenesis	Osteonecrosis Infection
Quality of soft tissues	Normal	Spasticity Obesity Muscle hyperdevelopment	Post-radiation fibrosis Small open wound	Tissue necrosis Infection Large open wound
Medical and medication problems	None	Smoker Hypertension Rheumatoid arthritis Other systemic arthritis	Diabetes Hemophilia Anemia Mild Immunosuppression Medication that inhibits bone formation	Moderate immunosuppression Chemotherapy
Planned elongation	For each centimeter, add one point to the total			

Interpretation: Normal: 0 to 6 points, moderate: 7 to 11 points, severe: 12 points or more.

Table 2: Case-matching between the two groups.

LON					EFL					PAIRING
CASE	ELONGATION CM	AGE	PALEY DIFFICULTY	ETIOLOGY	CASE	ELONGATION CM	AGE	PALEY DIFFICULTY	ETIOLOGY	
1	7	17	SEVERE	ACQUIRED	1	7	14	SEVERE	ACQUIRED	4
2	7.5	18	MODERATE	ACQUIRED	2	8	16	MODERATE	ACQUIRED	3
3	4	16	MILD	ACQUIRED	3	4.5	14	MILD	ACQUIRED	4
4	3.5	20	MODERATE	POST-TRAUMATIC	4	4	17	MODERATE	POST-TRAUMATIC	4
5	8	27	SEVERE	POST-TRAUMATIC	5	8.5	18	SEVERE	CONGENITAL	3
6	4	22	MILD	ACQUIRED	6	4	19	MILD	ACQUIRED	4
7	4	26	SEVERE	POST-TRAUMATIC	7	4.5	25	SEVERE	POST-TRAUMATIC	4
8	8.5	20	MODERATE	ACQUIRED	8	9	12	SEVERE	ACQUIRED	3
9	8.5	19	MODERATE	ACQUIRED	9	7	25	SEVERE	POST-TRAUMATIC	3
10	5	17	MILD	CONGENITAL	10	5	12	MILD	CONGENITAL	4
11	4	20	SEVERE	ACQUIRED	11	8	17	SEVERE	CONGENITAL	3
12	4	19	MODERATE	CONGENITAL	12	5	19	MODERATE	ACQUIRED	3
13	6	20	MODERATE	ACQUIRED	13	5	17	MODERATE	ACQUIRED	4
14	6	30	MODERATE	ACQUIRED	14	4.5	37	MODERATE	ACQUIRED	3
15	7	19	SEVERE	CONGENITAL	15	6	15	SEVERE	CONGENITAL	4

variables that we consider relevant according to the existing literature:

- External fixation time: Months elapsed between the implantation and removal of the external fixator;
- External Fixation Index (EFI): Defined as the time of external fixation divided by the length of elongation, measured in centimeters;
- Consolidation index (CI): Calculated as the months elapsed between the surgery and bone consolidation divided by the centimeters of elongation. The consolidation was considered to be complete when it was confirmed on the radiographs that at least three of the four cortices were intact or completely ossified [9-10];
- Assessment of clinical and radiological outcomes: We followed Paley's classification for the femur [4], distinguishing excellent, good, normal, and poor outcomes. The scale and parameters used are outlined in Table (3);
- Difficulties: We followed Paley's criteria [11], which distinguishes between problems, obstacles, and sequelae. Problems are defined as the difficulties that required non-surgical interventions to be solved. Obstacles needed surgical intervention to be solved. Sequelae are both intraoperative injuries and inconveniences that could not be solved before the end of the treatment; and
- Articular balance: The articular balance of the knee was taken as a parameter of specific articular functionality: range of full flexion from maximum extension preoperatively and subsequently at various times of treatment, from 0–120°.

Statistical methodology

According to Paley et al. [4], the EFI for the femur control group (bone elongation performed only with external fixation) is 1.7 (months/cm). We expected to reduce this EFI by 1 point, to 0.7, for the bone-elongation group with external fixation assisted by an intramedullary nail. For a confidence level of 95% and a power of 80%, we needed 12 patients per group. Assuming a 15% loss, we needed 15 patients in each group.

We performed a descriptive study with both groups in which the quantitative variables were summarized through their means, standard deviations, and ranges. Qualitative variables were characterized by their absolute and relative frequencies.

Table 3: Evaluation of the clinical-radiological outcomes of femoral elongation (Paley et al. 1997).

	Positive points (to be added to the final score)				Negative points (to be subtracted from the final score)			
	Excellent (25 points)	Good (20 points)	Normal (10 points)	Poor (0 points)	Excellent (0 points)	Good (5 points)	Normal (20 points)	Poor (30 points)
Range of knee mobility	Fixed deformity in flexion: 0° Flexion: > 120° Flexion: > 90% of preop. flexion	Fixed deformity in flexion: < 5° Flexion: 101–120° Flexion: 67–89% of preop. flexion	Fixed deformity in flexion: 6–15° Flexion: 70–100° Flexion: 50–66% of preop. flexion	Fixed deformity in flexion: > 15° Flexion: < 70° Flexion: < 50% of preop. flexion				
Amount of elongation achieved	Loss of less than 1 cm of that planned	Loss of between 1.1–3 cm of that planned	Loss of between 3.1–5 cm of that planned	Loss of > 5 cm of that planned				
Gait* (preop. to postop.). Points	0, 1 to 0	1, 2 to 1	0 to 1 or 1, 2 to 2	0 to 2				
Mechanical lateral distal femoral angle LDFA-a (degrees)	85–90	82–84 or 91–93	79–81 or 94–96	< 79 or > 96				
Pain** (preop. to postop.). Points					0, 1, 2 to 0 or 1 to 1	0, 2, 3 to 1	1 to 2 or 2 to 3	0 to 2, 3 or 1 to 3
Daily activities or work skill*** (preop. to postop.). Points					0, 1, 2 to 0	1, 2 to 1	1 to 2 or 0 to 1	0 to 2

Excellent: 95 to 100 points, good: 75 to 94 points, normal: 40 to 74 points, poor: less than 40 points.
**0 points: no jump, 1 point: slight jump, and 2 points: moderate jump.*
***0 points: no pain, 1 point: mild pain, 2 points: moderate pain, 3 points: severe pain.*
****0 points: complete daily activity and work, 1 point: reduced daily activity and work, 2 points: no regular daily activity or work.*

For the contrasts of hypotheses, after studying the normality in the distribution of the continuous variables using the Kolmogorov-Smirnoff test, we used Student's T-test in cases of normality and a non-parametric test in the opposite cases (Mann-Whitney U test), with the Wilcoxon signed-rank test for paired samples.

For the qualitative variables, we used the Chi-Squared test with the Yates correction if necessary and a study of standardized residues to analyze the direction of the associations.

All of the results are considered significant for a level $p < 0.05$. The analyses were performed with SPSS® v.19.0.

RESULTS

Comparability between treatment groups

We began the analysis by checking the homogeneity and comparability between both groups of patients. We analyzed parameters such as the amount of elongation, age, and the degree of difficulty of the procedure. The comparisons are presented in Table (2).

The mean amount of femoral elongation achieved using the LON technique was 5.8 cm (range 3.5–8.5 cm), compared to 6 cm (range 4–9 cm) in the femoral elongation group with no nail assistance. No statistically significant difference was detected between the two groups (p: 0.763) (Table 4).

The mean age in the LON group was 20.66 years (range 16–30 years), while in the EFL group, it was 18.86 years (range 12–37 years). Again, no significant difference was detected between the two groups (p: 0.365).

Finally, it was verified that there were no significant differences in the degree of difficulty between cases in the two groups (p: 0.717).

Thanks to these three preliminary analyses, we verified the comparability between the groups and proceeded to study the behaviors of the selected evaluation variables.

External fixation time and external fixation index

The patients in the LON group carried the fixator for a mean of 2.63 months (range 1.6–5.33 months), compared to 9.99 months in the EFL group (range 3.83–16.8 months). The difference was shown to be statistically significant, with $p < 0.0001$.

While analyzing the mean of the EFI, differences between groups were also verified ($p < 0.0001$). Patients with LON had their fixators implanted for a mean of 0.47 months per centimeter of elongation (range 0.37–1.9 months per centimeter of elongation), in contrast to the 1.64 months per centimeter of the EFL group (range 0.9–3.2 months per centimeter of elongation).

Consolidation index

Radiographs of the regenerated bone were taken with the same periodicity in both groups to evaluate the degree of bone consolidation.

In the femurs elongated with nail assistance, the CI was 1.27 months per cm of elongation (range 0.8–2.48 months per cm of elongation). In the other group, the mean was 1.64 months

Table 4: Length elongated, external fixation time, external fixation index, and mean consolidation index.

	LON	EFL	Statistical Sig. (p < 0.05)
Length gained (cm)	5.8	6	0.763
Age (years)	20.66	18.86	0.365
EF time (months)	2.63	9.99	< 0.0001
EF index (months/cm)	0.47	1.64	< 0.0001
Consolidation index (months/cm)	1.27	1.64	0.158

per centimeter of elongation (range 0.9–3.2 months per cm of elongation).

According to our analysis, there was no difference between the groups regarding the time required for bone consolidation (Table 4).

Clinical outcomes

In the LON group, the outcomes were classified as 8 excellent, 3 good, and 4 normal. Cases treated by isolated external fixation showed a total of 3 excellent, 9 good, and 3 normal cases in the group of patients whose femurs were elongated using EFL. There were no poor outcomes in either group. Statistically, there were no differences in clinical outcomes between the two techniques (p: 0.067).

Problems, obstacles, and sequelae

Analyzed as a whole, the complications found in both treatment groups presented significant differences (p: 0.002) in favor of the LON group (13 findings compared to 34). Each patient in the LON group had a mean of 0.87 complications, while each individual in the other group had a mean of 2.26 (Table 5).

Classifying them according to Paley's standards (problems, obstacles, or sequelae), we noted the distribution described in Table 5. In the LON group, there were 2 problems, 9 obstacles, and 2 sequelae, while in the EFL group, there were 11 problems, 16 obstacles, and 7 sequelae. The sequelae of the patients treated with LON were axial deviations without clinical repercussion, while the patients treated with EFL were distributed into three deaxations, three articular contractures with knee flexion inferior to 90°, and one subluxation of the knee (in a patient with anterior cruciate ligament (ACL) deficiency).

Complications related to the fixator screws were nine times more frequent in the EFL group than in the LON group, likely related to the increased use of screws (a mean of 4.06 screws per patient versus 7.26) and to the longer time of implantation of the external fixator.

Table 5: Complications by elongation method.

	LON	**EFL**	**Significance (p)**
General rate	0.86	2.26	0.002
Refracture rate	0.06	0.33	0.068
Articular contracture rate	0.13	0.66	0.03
Angular deviation rate	0.13	0.26	0.361

The number of refractures was also higher in the group not assisted by nails (1 versus 5), although statistical significance was not reached (p: 0.068). There were also no differences in the occurrence of axial deviations (p: 0.361).

Differences in knee contractures were recorded (p: 0.03). Two cases were found in the LON group, which were classified as obstacles and were solved with mobilizations under anesthesia. We were confronted with 10 contractures in the EFL group (3 problems, solved with physical therapy; 4 obstacles, solved with mobilization under anesthesia; and 3 sequelae, which required soft tissue release with reduced mobility below 90°).

Range of articular mobility of the knee

Finally, the degrees of knee flexion and their percent changes from the initial mobility (Figure 1) at the end of the distraction phase and at the end of the consolidation were evaluated. The preoperative mean flexion in the LON group was 116.6° versus 109.67° for the non-nail elongations. There were no significant differences between the two groups (p: 0.228), which, therefore, are comparable.

At the end of the distraction phase, a mean knee flexion of 54.13° (48% of the initial) was recorded in the LON group, compared to 39.6° (36% of the initial) in the EFL group. The flexion at the end of consolidation was 89.2° (79%) in the patients whose femurs were elongated with the aid of a nail and 52.6° (48.25%) in the patients given traditional treatment. The difference in flexion between both periods was statistically significant ($p < 0.0001$), indicating a faster rate of rehabilitation in the LON patients.

At two years after surgery, the flexion recorded in the LON group was 111.93°, with patients recovering 95.90% of their natural flexion capacity. In the EFL group, a flexion of 96.53° was recorded, representing 88.02% of the initial value. This difference was statistically significant ($p < 0.05$).

DISCUSSION

Although the study is subject to the limitations typical of a retrospective analysis and not having a high number of cases, the methodology used in the selection of the groups allows its homogeneity to facilitate the extraction of statistically relevant conclusions. The groups were comparable in age, elongated length, etiology, and degree of difficulty (a parameter encompassing twelve different variables).

Intramedullary nail support can significantly reduce the time of implantation of the external fixator and also the time of implantation per centimeter of elongation (EFI). Patients submitted to the traditional technique carried the fixator 3.79 times longer than those whose femurs were elongated by LON. The EFI was reduced 3.48-fold, which is in line with the bibliographic findings. In his study, Paley [4] confirmed a reduction of the external fixation time by 1.8-fold and a 2.4-fold reduction in the EFI. Simpson [12] also reduced the EFI 2.3-fold with respect to the technique without nailing.

With the data in our series, we cannot say that there are statistically significant differences with regard to the CI. Paley did find a difference in favor of elongations with an intramedullary nail, while El-Husseini [6] found no differences in a prospective randomized study.

There is doubt about whether the nailing can compromise the endoscopic vascularization, negatively affecting the quality of the regenerated bone. However, there appears to be evidence that the blood supply from the periosteum may increase after the milling and nailing, which is known to be particularly important for osteogenesis. In recent clinical studies, the LON technique has achieved the consolidation of regenerated bone without compromising bone quality [13].

Our study also reveals that in the series considered, the complications were fewer and of lower severity in the group assisted by intramedullary nail. Each patient in the traditional group faced a mean of 2.26 difficulties in treatment, compared to 0.86 in the LON group. This difference was significant from the statistical point of view (p: 0.01). Reviewing other related studies, we find that Kocauglu [14] recorded a rate of 0.43 complications per elongated segment, while Paley [4] noted an

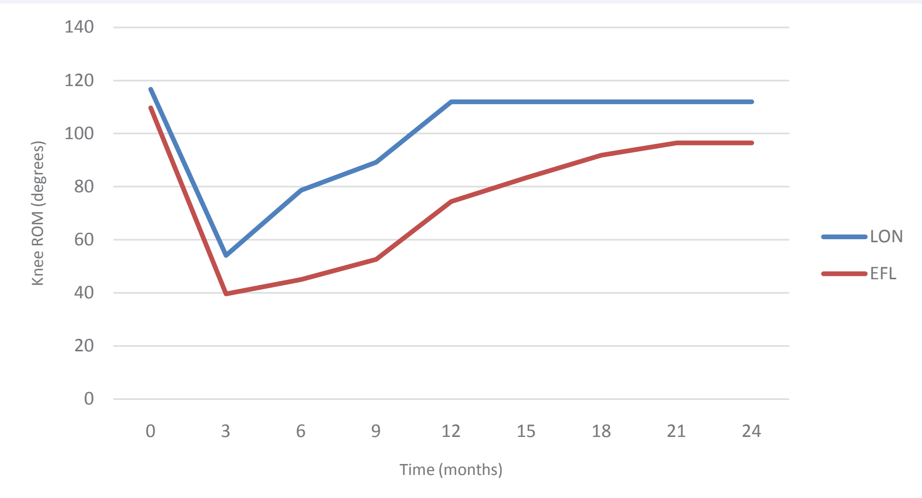

Figure 1 Range of motion (ROM) of the knee in the two groups.

occurrence of 1.4. In these two studies, the complications were also analyzed without computing the superficial infection of the screws because it is the most frequent and easy to treat difficulty. If we do not take into account superficial infections in our series, the difference remained significant (p: 0.01) in favor of LON, with 0.8 compared to 1.8 complications per elongated segment.

In a detailed analysis of the complications, we began by studying the axial deviations of the segments. Although these deviations were more common in the group without nailing (rate of 0.13 versus 0.26), the difference did not reach statistical significance. Theoretically, the nail should help to compensate for the almost inevitable varus deformity that occurs during elongation. However, some authors [4] indicate the valgization of the mechanical axis that occurs as a consequence of performing an elongation following the anatomical axis as a possible drawback of the LON technique. Such a deformity would be easily correctable in a traditional procedure but impossible to control with an intramedullary nail that will support the bone from the canal. In fact, in our LON series, we found a case of valgus deformity (with mechanical axis deviation greater than 10 mm) that did not require secondary treatment. In his article, Paley noted that 8 of the 32 segments elongated with the assistance of a nail showed axial deviations, which infers a rate very close to the one found in our series (0.25).

No significant differences were found in the refractures section (p: 0.068), although the rate of occurrence was also in favor of the LON technique (0.06 versus 0.33). In general, this problem occurs as a consequence of the complete mineralization or reduced diameter of the regenerated bone, of the reduced diameter of the regenerate, or of the muscle tension. Fractures can also occur through the screw holes. From a theoretical point of view, one could expect a greater number of fractures in cases elongated with the aid of a nail because the fixator is removed when the callus is still immature, leaving a locking nail as its only support. To avoid this issue, we protected our patients from the load with crutches until a greater density was verified in the regenerated bone. In the LON group, the only fracture that occurred was through the path of one of the screws of the external fixator in the absence of distraction by the grip of the nail.

In the literature, we find few cases of consolidation delay or pseudoarthrosis after osteogenesis at distraction. In the article by Kocauglu [14], delays of consolidation were observed twice. In both cases, the union was achieved after applying a bone graft. In our opinion, we believe that the reason for the delay of consolidation generally has to do with previous surgical interventions that produce a devitalized bone segment. We consider that for patients who have had previous surgery, osteotomies should be avoided through the anomalous segment and that it is preferable to perform them in distant places (for example by retrograde LON technique), preserving the periosteum and the surrounding musculature. Although the milling of the canal could theoretically damage the endoscopic circulation and affect the quality of the bone regenerate, in clinical practice, this idea has not been corroborated, at least for the femur [15]. It seems likely that the damage caused by the milling is compensated by the revascularization that occurs after it, by the greater stability that the insertion of the nail contributes, and by an early return to the load [12].

The premature consolidation of the elongation callus (or the impossibility of distracting the osteotomy) occurred in two of the segments treated with nails and in none of the EFL group. Reviewing the literature, we find that in the first published series, the main cause of premature consolidation was the lack of milling for fear of damaging the vascularization of the callus. However, it is now observed (at least in the femur) that overmilling does not prolong the time of consolidation of the regenerated bone [15]. In our series, we can affirm that the CI was lower for the group of bone elongation by LON with respect to the EFL group, though the difference was not statistically significant.

A drawback of the LON technique is the possibility of converting a local infection of the screw tract into deep intramedullary sepsis. In fact, in the field of traumatology, sequential change protocols are usually applied when a transition is made from an external fixator to a nail in the treatment of open fractures [14]. However, the arrival of hydroxyapatite-coated screws has reduced this type of problem, with the result that there are no high rates of deep infection in elongations assisted by a nail [16,17]. In fact, in our series, we observed no deep infections after at least two years of follow-up. However, we believe that the previous presence of infection should be a key consideration when choosing the elongation method. Osteomyelitis is not common when using the usual technique, but it can occur in cases treated with LON. Gordon et al. [5] showed two cases of osteomyelitis in nine patients, and Song et al. [18], recorded three cases in a series of twenty-two patients.

Regarding articular mobility, the LON group showed a faster recovery and greater mobility at the end of the distraction, consolidation, and follow-up phases (always with statistical significance). We believe that the reasons for these differences are the shorter external fixation time and the lower number of pieces used, which reduces muscle transfixion. Paley et al. [4], also found that the mean knee flexion at the end of the distraction phase was significantly better in elongation cases using the LON technique (58° versus 47°). The same occurs at the end of consolidation. Knee stiffness (and especially flexion contracture) is common after femoral elongation and may be a result of muscle contracture or adhesions during the course of treatment [19].

Despite the advantages that the LON technique seems to show, it is not a method applicable to all patients. In subjects with immature skeletons, anterograde nailing through the piriform fossa may damage the vascularization of the proximal femoral epiphysis and lead to avascular necrosis of the femoral head. If one opts for insertion through the greater trochanter, there is a risk of stopping trochanteric growth and of a valgus deformity of the femoral neck [20]. Needless to say, classical retrograde nailing is not a technique applicable in pediatric patients. Therefore, the LON technique is not recommended for growing patients.

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In light of the results obtained, the following conclusions can be drawn from this study:

- The external fixation time in patients treated with LON was lower than in patients treated with the EFL technique. The mean reduction of time was quantified as 7.36 months. This difference implies a reduction of 3.79-

fold with respect to the conventional technique.

- The EFI was reduced by an average of 35.1 days per centimeter of elongation when using the nail. This implies a reduction of 3.48-fold in comparison with the classic technique.
- The CI did not show significant differences between the two techniques (1.27 months/cm for the LON technique versus 1.64 months/cm for the EFL).
- External fixation assisted by LON presented a lower rate of complications compared to EFL (0.86 per LON patient versus 2.26 suffered by patients in the conventional group).
- More rapid functional recovery and greater articular mobility in the knee were achieved with external fixation assisted by a nail when compared to the traditional technique. The ranges were 54.13° and 39.6° at the end of the distraction phase. At the end of consolidation, 89.2° and 52.6° were recorded; at the end of treatment, 111.93° and 96.53° were observed. All results are significant and favor the LON technique.

From all of the above and taking into account some caveats and recommendations that we have made throughout the study, we can conclude that osteogenesis on distraction with external fixation assisted by LON is a more effective therapeutic procedure than EFL for elongations of the femur in terms of the external fixation time, the external fixation index, the rate of complications, and the range of articular mobility. However, no advantages have been shown in the CI.

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