Elastic intramedullary nailing as a complement to Ilizarov’s method for forearm lengthening: A comparative pediatric prospective study

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KEYWORDS
Forearm discrepancy; Lengthening; ESIN; Limb deformities; Circular external fixation

Summary

Purpose: Most of the techniques for forearm lengthening involve external fixation to achieve stability and provide progressive distraction. We introduce the use of elastic stable intramedullar nailing (ESIN) in combination with external circular assembly for the procedure. The purpose of this prospective study was to compare Ilizarov’s classical technique with this combined technique.

Methods: Fifty-seven patients, with forearm length discrepancies or deformities either congenital or acquired, were prospectively followed-up. Patients were divided in two groups: 35 had only external fixation, and 22 had external fixation-ESIN combined techniques. Patients were assessed for clinical and radiographic outcome with a mean follow-up of 21 months after external device removal.

Results: Overall lengthening was 45.0 mm. Healing index (HI) was 22.2 d/cm with the combined technique, and 32.0 d/cm with external fixation. HI was 30% better when ESIN was used, for congenital and for overall cases. Combined technique has a lower complication rate.

Conclusion: Although forearm lengthening still remains a time-consuming procedure, ESIN can shorten external fixator wearing time. No additional complication occurred and bony complications seem to be limited by the nails. We recommend this technique, which we now use for most of our patients undergoing limb lengthening.

Level of evidence: Level IV.

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Introduction

Lengthening of arm bones, in particular of the forearm is a difficult technique that is often used for congenital or acquired deformities. Acute lengthening \cite{1} requires a bone graft for additional length and the amplitude is limited.
by soft tissues. Progressive lengthening with an external device, followed by a bone graft is a possible technique, but this is a two-step surgical procedure that has the disadvantage of requiring bone harvesting.

Lengthening by callotasis has been described [2, 3] based on the principles of Ilizarov [4–8] and several series have reported good results with this technique in the forearm [3, 9, 10]. Lengthening and correction of deformities in three dimensions is possible with the Ilizarov technique. Moreover, significant distraction is possible thanks to gradual distraction of the soft tissues. One of the main disadvantages of this technique is the time necessary to obtain lengthening then union of the regenerate bone, which is a source of discomfort to the patient, because he must wear an external fixation device throughout the bone-healing phase. At the same time, the circular fixation device is perfectly well adapted to the size of the two forearm bones, because of the use of several small pins.

We present a prospective series of 57 consecutive young patients who required progressive forearm bone lengthening. A circular external fixation device was used associated or not with elastic stable intramedullary nailing (ESIN), a combination which has already been shown to be effective for progressive bone lengthening, both in the forearm [11], and other locations [12, 13] (Fig. 1).

The aim of this series was to compare the results of these two approaches for successful lengthening (duration, amplitude) and complications.

Patients and methods

Patients

Fifty-seven children underwent surgery for forearm lengthening performed by the same senior surgeon in two different hospitals. All patients presented with forearm length discrepancies with various angular deformities. The mean age at surgery of the 30 girls and 27 boys was 11 years old (3–16). Results were evaluated a mean 21 months after removal of the external fixation device (3 months–5 years).

Forty-seven patients (82.5%) presented with a congenital deformity and the 10 others (17.5%) with an acquired deformity. Congenital deformities included 32 radial defects (18 aplasias and 14 hypoplasias) and 15 ulnar defects associated with dislocation of the radial head. Acquired deformities included sequelae from osteomyelitis of the distal radius in three cases and growth plate traumas (seven cases).

Patients were divided into two groups (Table 1): group 1 was treated with circular external fixation alone and group 2 with circular external fixation combined with ESIN. Inclusion in one or the other group was left up to the parents. The ESIN technique was presented as potentially faster, but with the disadvantage of requiring additional general anesthesia to remove the intramedullary material.

Surgical technique

The principles of Ilizarov were always followed: percutaneous osteoclasis by osteotomy to respect perosteal and endomedullary vascularization, then ESIN. An Ilizarov fixator was used 55 times and a Taylor Spatial Frame® (TSF) twice, both devices are based on a similar principle [14]. The choice of circular rather than a unilateral fixation was deliberate, because in a certain number of cases of lengthening of both forearm bones, circular fixation makes it possible to use wires and not screws thus making fixation of the soft tissues less bulky. Lengthening itself began 4–5 days after surgery, and the speed of distraction was adjusted according to the development of the bone regenerate as seen on consecutive X-rays.

Lengthening was obtained in increments of 0.25 mm: Usually daily lengthening was 1 mm/day or four daily lengthening sessions.

Lengthening in several daily sessions made it possible to obtain nearly continuous distraction, which is better tolerated by the soft tissues and which respects Ilizarov’s principles [15]. The speed of lengthening was then adapted to the quality and height of the bone regenerate (less than 2 mm: lengthening was accelerated, more than 10 mm: lengthening was slowed down). Lengthening did not have to be stopped in any of the patients in this series. Finally, patients were encouraged to perform rehabilitation on their own to improve later functional recovery. The structure of the external fixation device was adapted on a case-by-case basis in relation to the deformity and the planned lengthening protocol. We mainly used Kirschner wires and occasionally olecranon nails.

The radial osteotomy was always on the distal metaphysis or diaphysis (depending the site of the deformity). The ulnar osteotomy was mainly in the proximal third of the diaphysis and on the proximal metaphysis, and could be unilateral or bifocal. In case of ulnar hypoplasia with dislocation of the head of the radius, the ulna was lengthened first, then the head of the radius was progressively reduced, then the radius was lengthened if necessary. Simultaneous realignment of a radial club hand was possible. Rings were placed so that hinged correction was found along the angulation correction axis (ACA) on the convex side of the deformity.
Elastic intramedullary nailing as a complement during the forearm progressive lengthening

In group 2 (external fixation + ESIN), we used 1.5 or 2 mm titanium or steel intramedullary pins. The surgical sequence was: placement of external fixation with several pins, corticotomy as previously described, ESIN procedure (systematic nailing of both bones), and finally placement of additional pins for external fixation. This two-step placement of external fixation seemed to simplify the ESIN procedure and the second step of external fixation was not more difficult, because the ESIN system did not fill the entire medullary cavity.

Clinical and radiological evaluation

Results of lengthening were assessed in relation to the amplitude or the amount of lengthening in mm, the lengthening index (ratio of the amplitude of lengthening/initial bone length as a percentage), the healing index (HI) (ratio of the amount of lengthening/duration of external fixation in days/cm), and duration of lengthening and external fixation (in days). Analysis of the healing index shows the overall speed of the procedure (lengthening and healing) and helps compare patients, even if lengthening amplitudes are different.

Clinical and radiological follow-up was performed by the same senior surgeon. X-rays were performed preoperatively, then every 2 weeks during the lengthening phase then 1 month after the beginning of the union phase. X-rays were then performed every 2–3 weeks depending upon how bone union progressed, and whenever fixation devices were removed or modified. Final lengthening was measured on X-rays at the last follow-up by determining the distance between the osteotomy scars that were still visible at this stage. All other indexes were calculated from this value. No intermediate measurements were obtained, because the forearm could not be placed close enough to the X-ray cassette because of the bulky fixation device, which would result in inexact measurements. Complications were noted and classified according to Caton [16] (Table 2).

Table 1 Amplitude of lengthening and Healing Index by group.

<table>
<thead>
<tr>
<th>Type of fixation</th>
<th>Number of patients</th>
<th>Age (years)</th>
<th>Lengthening (cm)</th>
<th>Lengthening index (%)</th>
<th>Total duration of treatment (days)</th>
<th>Healing index (days/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congenital</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1: EF</td>
<td>28</td>
<td>11 ± 0.71</td>
<td>4.2 ± 0.21</td>
<td>26.2 ± 1.9</td>
<td>120.8 ± 6.25</td>
<td>30.2 ± 1.39</td>
</tr>
<tr>
<td>Group 2: EF + ESIN</td>
<td>19</td>
<td>9.9 ± 0.99</td>
<td>5.7 ± 0.37</td>
<td>32.1 ± 2.37</td>
<td>117.8 ± 8.29</td>
<td>21.6 ± 1.41</td>
</tr>
<tr>
<td>Acquired</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1: FE</td>
<td>7</td>
<td>13.3 ± 0.6</td>
<td>2.6 ± 0.32</td>
<td>12.3 ± 1.42</td>
<td>105.3 ± 19.19</td>
<td>39.1 ± 4.45</td>
</tr>
<tr>
<td>Group 2: FE + ESIN</td>
<td>3</td>
<td>13 ± 0.58</td>
<td>3.8 ± 1.36</td>
<td>16.7 ± 4.67</td>
<td>85.3 ± 12.99</td>
<td>26 ± 6.23</td>
</tr>
<tr>
<td>Entire series</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1: EF</td>
<td>35</td>
<td>14.1</td>
<td>3.9 ± 0.21</td>
<td>23.4 ± 1.81</td>
<td>117.7 ± 6.24</td>
<td>31.98 ± 1.52</td>
</tr>
<tr>
<td>Group 2: EF + ESIN</td>
<td>22</td>
<td>10.6</td>
<td>5.46 ± 0.38* (P = 0.0002 St)</td>
<td>30 ± 2.4</td>
<td>113.4 ± 7.68 (P = 0.6679 St)</td>
<td>22.2 ± 1.44* (P = 0.0001 St)</td>
</tr>
</tbody>
</table>
| EF: external fixator; ESIN: elastic stable intramedullary nailing; MW U: Mann and Whitney U test; St: student test.

*Statistically significant difference for the results.

Statistical analysis

Statistical analysis was performed with STATPLUS® software. Means and standard deviations were calculated for continuous variables (duration of lengthening and fixation, amplitude of lengthening, healing index). Comparison of results and complications between the two groups were evaluated with the Student t test and the Mann and Whitney U test for continuous variables, the Fisher’s exact or Chi² tests were used for qualitative variables. P < 0.05 was considered to be significant.

Ethics

This study was performed in accordance with national ethical guidelines from the Committee for Clinical Research in Humans and the 1975 Declaration of Helsinki revised in 2000.

Results

Efficacy of lengthening: amplitude of lengthening and healing index

Mean lengthening was 45.0 mm. The results in each subgroup are reported in Table 1. The duration of external fixation was not different between the two groups while the amplitude...
of lengthening was 40% greater in group 2 (combined technique). The healing index (HI) was 30.2 d/cm in group 1, and 21.6 d/cm in group 2 for congenital etiologies (Fig. 2). The difference was statistically significant; the combination of ESIN and external fixation improved the HI by 29.5% (Fig. 3). Although the HI was reduced in group 2 for acquired deformities the difference between the two groups was not statistically significant. The overall difference in the HI was significant for the entire series with a decrease of 30% in group 2.

Table 2 Classification of complications during limb lengthening according to Caton [16].

<table>
<thead>
<tr>
<th>Category</th>
<th>Goals of lengthening achieved</th>
<th>Complications and sequellae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1</td>
<td>Yes</td>
<td>None. Minor incidents which resolved spontaneously at the end of the lengthening program</td>
</tr>
<tr>
<td>Category 2</td>
<td>Yes</td>
<td>Complication without sequellae, but requiring additional and unplanned surgery</td>
</tr>
<tr>
<td>Category 3</td>
<td>No</td>
<td>Major complications resulting in sequelae, lengthening interrupted because of complications, total lengthening not obtained</td>
</tr>
</tbody>
</table>

Figure 2  A. Preoperative X-ray: young 9 year-old-girl presenting with radial club hand. B. Primary realignment of the hand, then progressive lengthening of the two bones, without ESIN. C. Ongoing lengthening. D. Final X-ray results: Lengthening: 6 cm for the radius and 4 cm for the ulna. Duration of external fixation 158 days, or a healing index of 26.3 d/cm.

Figure 3  A. Preoperative X-ray: six-year-old boy presenting with an ulnar club hand. B. Primary realignment of the hand, then progressive lengthening of both bones, associated with ESIN in each bone. C. Final radiographic result: lengthening: 3.5 cm for the radius (28%) and 7 cm for the ulna (83%). The healing index is 17.1 d/cm.
Complications

Complications were classified according to the Caton classification. More than half the complications were grade 1 and they did not influence the final result (Table 3). The frequency of grade 2 complications was similar between the two groups. There were no grade 3 complications when external fixation was associated with ESIN (group 2). Bone complications were more frequent in group 1 (external fixation alone). The development of joint stiffness was similar in both groups (fingers in 8.8%, pronosupination in 7%, and elbow flexion contracture in 3.5% of cases). No deep infections were observed in any of the patients. Antibiotics were not used to manage pin tract infections in any patients. All superficial infections were treated by applying a moist anti-septic chlorhexidine bandage. If the pin tract infection was not controlled after several days of local treatment, the pin was replaced and a new insertion site.

Distraction neuropathies were the most frequent complication, and required removal of pins or slowing the lengthening procedure. All neurological complications had resolved at the final follow-up.

Discussion

This prospective study included 57 patients who underwent forearm lengthening, a fairly rare indication.

We have described the details of lengthening and the development of complications. Nevertheless, the etiologies in our series were heterogeneous, as numerous different diseases can result in length discrepancies or deformities of the forearm. In addition the age at diagnosis and management varied in the patients in this study, as well as the specific details of the fixation device and the lengthening protocol, which were decided on a case-by-case basis, depending upon each deformity.

Nevertheless, certain parameters were similar and can be analyzed and compared. In this series mean lengthening was 4.5 cm and the mean lengthening index was 30%. These results are in the low range compared to other series of forearm lengthening in the literature [17,18]. Although lengthening indexes of 50% have been described [19,20], the number of complications was high, in particular of the bone with bowing or fracture of the regenerate bone [9]. If significant lengthening is necessary, we recommend a two-step procedure [9,21] or a double osteotomy [19]. Moreover, perfect symmetry does not seem necessary to obtain a good functional result in the upper limb [19].

The HI results in group 1 were similar to those in the literature (30.2 d/cm in cases of congenital disease and 39.1 d/cm in acquired). Other authors often note HI values of between 40–60 d/cm [9,17,19,22,23]. Horii [18] found a relationship between the age of the patients and the HI in 35 cases of lengthening for congenital deformities and suggests that the speed of lengthening should be adapted to the initial cause of the disease. The HI was markedly better in group 2 which associated external fixation and ESIN (21.3 d/cm for congenital disease 26.0 d/cm for acquired deformities). These results are the lowest of all those in the literature. The difference between the results in group 1 and group 2 were statistically significant for the entire series and for the sub-group of congenital deformities. The mean improvement in HI with the association of ESIN and an external fixator was 30%.

Lengthening over an intramedullary device combined with an external fixator has been studied in the lower limbs [24–29]. The intramedullary devices used were often bulky, requiring intramedullary nails which we did not feel should be used in a child because of the presence of growth plates. Nevertheless, Paley et al. showed [24] that results of lengthening over an intramedullary nail associated with an external fixator were better in a population of young adults than an external fixator alone. That comparative study found that the duration of fixation was reduced by half, a lower frequency of refractures and secondary deformities in the bone regenerate, and faster rehabilitation of the knee. Saraph et al. [30] reported results of tibial lengthening in a child using flexible Ender nails (less traumatic for endomedullary vascularization and growth plates), for femoral lengthening in nine patients and concluded that the duration of external fixation may be reduced, although the study was not comparative. In the same way, Aston et al. [31] recommends proximal osteotomy of the femur over a Rush nail to limit fracture complications during lengthening of congenital short femurs. We reported the benefits of the association of our circular external fixator-ESIN in a study of the lower limb [12,13] and a study combining upper and lower limbs [12,13]. Launay et al. [11] reported a series of 10 forearm lengthenings with good results but osteotomies only involved one bone so that a unilateral fixator was used, and bone axis correction was performed by subtraction osteotomy at the initial osteotomy site. The increase in HI can be explained by early removal of the external fixator (before complete union is obtained): stability is then achieved by the ESIN until union is complete. This early removal of the external fixation device also improves the comfort for young patients and reduces the psychological trauma. If an intramedullary device is not used, any attempt to reduce the HI results in a higher complication rates, with fractures of the bone regenerate or bowing [17].

There was only one case of delayed union, which did not require additional surgery. Indeed, most of our complications occurred in group 1 and were similar to those described in the literature [9,19,22,23]. The results in the study by Launay et al. report four out of 10 cases of delayed union with revision surgery by bone graft. This could be due to greater devascularization at the subtraction osteotomy site [11]. ESIN can limit deformities after removal of external fixation [12,13] as well as the risks of fracture. Moreover intramedullary nails guide growth of the bone regenerate during the distraction phase, limiting the risk of translation and thus a number of additional surgical procedures. There were no complications, which were specifically due to ESIN in our series.

Patients underwent careful rehabilitation and wore braces [9] and even in certain cases fixation of the hand with pins, although we feel that the position of the pins plays an important, underestimated role in the development of finger stiffness. In this respect, finger flexors should never be pierced (Fig. 1) to permit full vascularization and range of motion. Around the elbow, the goal should be to preserve full flexion: we recommend the use of open circular hoops: (anterior opening) to reduce

Table 3 Complications by group.

<table>
<thead>
<tr>
<th>Complications</th>
<th>Group 1: External fixation (EF) n = 35</th>
<th>Group 2: EF + ESIN n = 22</th>
<th>P = 0.006 (Pearson Chi² test)</th>
<th>P = 0.004 (Fisher exact test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone</td>
<td>17.1% (6 patients) delayed union</td>
<td>4.5% (1 patient) delayed union</td>
<td></td>
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<tr>
<td></td>
<td>consolidation</td>
<td></td>
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<tr>
<td></td>
<td>11.4% (4 patients) bowing of bone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>regenerate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8.6% (3 patients) fracture of bone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>regenerate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.9% (1 patient) pseudarthrosis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infection</td>
<td>0 deep infection</td>
<td>0 deep infection</td>
<td>P = 0.543 (Pearson Chi² test)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20% (7 patients) superficial infection</td>
<td>9.1% (2 patients)</td>
<td>P = 0.458 (Fisher exact test)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2 pin replacements)</td>
<td>superficial infection</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(pins were not changed)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caton</td>
<td>Category 1</td>
<td>54.3% (19 patients)</td>
<td>P = 0.532 (Pearson Chi² test)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Category 2</td>
<td>34.3% (12 patients)</td>
<td>P = 0.264 (Fisher exact test)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Category 3</td>
<td>11.4% (4 patients)</td>
<td>P = 0.413 (Pearson Chi² test)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0% (0 patients)</td>
<td>P = 0.771 (Fisher exact test)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>P = 0.532 (Pearson Chi² test)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>P = 0.151 (Fisher exact test)</td>
<td></td>
</tr>
</tbody>
</table>

Conclusion

In our experience, lengthening of the forearm with a circular external fixator is a reliable technique. We recommend associating this external fixation with ESIN in each bone in the case of congenital deformities, because complications are less frequent and the duration of external fixation is markedly reduced. We also recommend this association in case of acquired deformities, even though our results were not statistically significant in this sub group.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References

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