

# Lengthening Nails for Distraction Osteogenesis: A Review of Current Practice and Presentation of Extended Indications

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## ABSTRACT

**Purpose:** Circular frames have been the gold standard of treatment for complex deformity corrections and bone loss. However, despite the success of frames, patient satisfaction has been low, and complications are frequent. Most recently, lengthening nails have been used to correct leg length discrepancies. In this article, we review the current trends in deformity correction with emphasis on bone lengthening and present our case examples on the use of lengthening nails for management of complex malunions, non-unions, and a novel use in bone transport.

**Materials and methods:** A nonsystematic literature review on the topic was performed. Four case examples from our institute, Brighton and Sussex University Hospitals, East Sussex, England, UK, were included.

**Results:** New techniques based on intramedullary bone lengthening and deformity correction are replacing the conventional external frames. Introduction of lengthening and then nailing and lengthening over a nail techniques paved the way for popularization of the more recent lengthening nails. Lengthening nails have gone through evolution from the first mechanical nails to motorized nails and more recently the magnetic lengthening nails. Two case examples demonstrate successful use of lengthening nails for management of malunion, and two case examples describe novel use in management of non-unions, including the first report in the literature of plate-assisted bone segment transport for the longest defect successfully treated using this novel technique.

**Conclusion:** With the significant advancement of intramedullary lengthening devices with lower complications rates and higher patient satisfaction, the era of the circular frame may be over.

**Keywords:** Deformity correction, Distraction osteogenesis, Lengthening nails, Malunion, Non-union.

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## INTRODUCTION

Circular frames have been the gold standard for treating bone defects, leg length discrepancies, malunion, and non-union. However, the time required to wear the circular frames can be lengthy, patient satisfaction is generally low, and complications such as refractures, pin site infections, and amputation rate are significant.<sup>1</sup>

In the recent years, the use of fully implantable systems for limb lengthening have helped to overcome many problems associated with the use of circular frames. In our institution, we have now successfully used lengthening nails for non-union, malunion, and bone defects. In this article, we aim to present an overview of these cases with a review of the literature.

## EVOLUTION OF CIRCULAR FRAMES

Ilizarov discovered the principle of distraction osteogenesis when using circular frames for treatment of fracture non-unions, and he observed callus formation when one patient lengthened his frame rather than compressing it.<sup>2</sup> Circumstances like the presence of poor skin quality, multiplanar deformity, history of infection, and lack of postoperative adjustability are all factors that favored the use of circular frames over internal fixation methods.<sup>3</sup>

Taylor spatial frame (TSF) was later introduced as a computer software-based fixator allowing more accurate corrections of multiplanar deformities.<sup>4</sup> TSF has been successfully used for correction of pediatric deformities, including complicated fractures, malunions with subsequent growth arrest, Blount disease, skeletal dysplasia, and congenital short femur and tibia. Eidelman et al.<sup>5</sup> reported anatomically correcting the

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abovementioned deformities in all but 1 of 31 patients. Their most common reported complication was superficial pin tract infection (45%).

One of the biggest challenges with circular frames has been tolerance by the patient, and attempts have been made to reduce frame time. Rogers et al.<sup>6</sup> described acute correction of distal femur fracture deformities using intraoperative TSF followed by application of percutaneous locking plate or intramedullary nail. Deformity correction and restoration of the mechanical axis were achieved in all 8 cases with no complications.

The following hybrid techniques aim to decrease frame time in order to minimize complications and prevent recurrence of deformities following frame removal:

### Lengthening then Plating

Combining a circular fixator with a plate has been described to prevent loss of fixation and protect against bending of the regenerated bone after frame removal.<sup>7</sup> Iobst and Dahl<sup>8</sup> described this technique as suitable for the pediatric age-group with open physis as an alternative to lengthening nails. The mean duration of external fixation was 45 days. All six patients in the series achieved solid union of the lengthening site with mean lengthening of 3.52 cm, which represented an average of 14.6% of the overall bone length.

### Lengthening and then Nailing Technique

Rozbruch et al.<sup>9</sup> presented the lengthening and then nailing (LATN) technique in which a frame is used for gradual distraction and then a reamed intramedullary nail inserted to support the bone during the consolidation phase, allowing early removal of the external fixator. They compared this technique to the conventional external fixator method for lengthening in a retrospective case-matched study on 73 limbs (39 limbs LATN vs 34 limbs conventional). The LATN patients wore the frame about a quarter of the time of the Ilizarov group, and bony union occurred in less than half the time of the Ilizarov group.<sup>9</sup> It was presumed by the author that these results might be due to a surge in growth factors caused by reaming through the regenerated bone similar to the concept of exchange nailing for femoral and tibial non-unions. Their incidence of deep intramedullary infection was 2.5%. These results were supported by Xu's<sup>10</sup> systematic review and meta-analysis of LATN (183 limbs) compared to Ilizarov (171 limbs).

### Lengthening over a Nail Technique

The techniques of lengthening over a nail (LON) and transport over a nail (TON) are effective in decreasing external fixator duration and consolidation time. As an added benefit, the nail protects the regenerated bone from fracture after external fixator removal.<sup>11</sup> A prospective randomized controlled trial by El-Husseini et al.<sup>12</sup> comparing LON to Ilizarov in 31 limbs found that overall LON offers a significantly shorter period of external fixation and fewer complications. In a retrospective study over 34 limb lengthening procedures with an average follow-up of 76 months comparing LON vs the intramedullary skeletal kinetic distraction (ISKD) first-generation lengthening nail, it was found that the LON group had fewer complication rates and secondary procedures compared to the ISKD group.<sup>13</sup> However, a more recent study by Fragomen et al.<sup>14</sup> showed that later generations of magnetic lengthening nails fared better in terms of accuracy and fewer complication rates when compared to LON.

Despite the advantages of this technique, the risk of developing deep medullary infection is a concern. This was proven to be very low in later series and mainly related to cases with a history of open fractures.<sup>15</sup> In addition, Chaudhary<sup>16</sup> demonstrated no infections in his 27 cases, while Kocaoglu et al.<sup>17</sup> in their 42 LON cases reported very low infection rates.

### LENGTHENING OVER A PLATE TECHNIQUE

Inspired by the LON technique, a plate has been used to replace the nail. Lengthening over a plate (LOP) both reduces the risk of deep medullary infection associated with LON and in the same time expands the indications of this technique to include the pediatric age-group without the risk of damage to the physis. A problem with this technique is that the plate might become more prominent, as it is pushed by the distal lengthened segment causing skin complications. A modification of this technique is the use of

a slotted lengthening plate, where the distal segment is also fixed through the lengthening slot.<sup>18</sup>

### EVOLUTION OF INTRAMEDULLARY LENGTHENING

Intramedullary nails rely on the periosteum for osteogenesis and callus formation.<sup>19</sup> Recent studies have demonstrated damage to the periosteum is more detrimental than endosteum for callus formation. Kojimoto et al.<sup>20</sup> in a rabbit model performed a subperiosteal osteotomy on the tibial diaphysis and then slowly distracted using a dynamic external fixator. When the periosteum was removed at the operation, callus formation was markedly disturbed, and there was failure of bone lengthening. Scraping of endosteum, in contrast, did not have a pronounced effect.

Reaming of the medullary canal has been shown to increase periosteal blood flow and stimulates periosteal new bone formation.<sup>21</sup> Moreover, the products of reaming have osteo-inductive properties owing to their abundance in osteoblasts and multipotent stem cells.<sup>22</sup> It has been observed that there is increased bone mineral content and density in the callus segment compared to controls after intramedullary nailing in a rat femur model.<sup>23</sup> These effects of intramedullary reaming on union rates has already been established in the literature in exchange nailing for non-unions of the femur and tibia with reported rates of union ranging between 78 and 100%.<sup>24–26</sup>

Early attempts at implementation of intramedullary lengthening were dated as early as 1956. Bost and Larsen<sup>27</sup> reported use of an external fixator for bone lengthening over an intramedullary nail. This idea developed into using only a nail as a primary distractor with the aim of eliminating the need for external fixator pins. This reduced the complications related to external fixators, achieved faster rehabilitation, and conferred more stability. First intramedullary lengthening nails were lengthened through an external transcutaneous connection such as a hydraulic pump connected to the nail tip that drives the telescoping mechanism of the nail.<sup>28</sup> Later advances eliminated the need for external connections, and the nails became completely implantable.<sup>29</sup>

Three types of completely implantable intramedullary lengthening nails were developed:

#### Mechanical Nails

Mechanically activated nails, such as the intramedullary skeletal kinetic distractor nail (ISKD) and the Albizzia nail, were the first generation of intramedullary lengthening nails. Lengthening is controlled by the patient themselves. The ISKD is designed to gradually lengthen for a predetermined distance and then stop controlled by the patient performing small rotational oscillations of the limb (3°). The ISKD came with an external handheld monitor that could track the rate of distraction.

Early results from use of ISKD were promising. Cole et al.<sup>30</sup> in prospective study reported the first clinical results from the use of 20 ISKD devices to achieve an average lengthening 49 mm in femoral and tibial defects. No implant-related infections or non-unions were observed. These results were supported by Hankemeier et al.<sup>31</sup> in a small case series achieving an average lengthening of 31 mm.

However, reports of distraction problems started to appear and were mostly due to dysfunction within the ratcheting mechanism. Burghardt et al.<sup>32</sup> reported an overall failure rate of 6.2% in 242 lengthening nails over 8 years. The commonest modes of failure were nail fracture followed by failure of the lengthening mechanism. Another serious complication was a sudden and acute

distraction by the nail known as “the runaway nail”. This was thought to be due to oversensitivity of the clutch mechanism resulting in activation by physiological movements or muscle contractions. Kenaway et al.<sup>33</sup> achieved average length gain of  $4.3 \pm 1.6$  cm with correction of deformity in 57 ISKD but a 21% failure rate.

On the other hand, The Albizzia nail (DePuy, Villeurbanne, France) is similar in concept to the ISKD but differs in that its lengthening mechanism is activated by rotations of 20° around the horizontal axis. This has decreased the possible “runaway nail” complication seen in the ISKD. However, the large magnitude of torsion sometimes resulted in severe pain, and the lengthening mechanism was found to be imprecise. In a prospective study by Mazeau et al.<sup>34</sup> on 36 Albizzia nails, in three cases, there was failure of the distraction mechanism, in six the lengthening was achieved with a second procedure, and eight patients required one ratcheting or more under general anaesthesia.

### Motorized Nails

Motorized fully implantable nails such as the Fitbone (Wittenstein Intens, Igersheim, Germany) use an external electronic signal from a remote-control system for mechanical distraction. Rozbruch et al.<sup>35</sup> in his review article found motorized lengthening nails to be superior to mechanical nails in terms of accuracy and lower rate of complications.

Despite the enhanced precision of distraction in comparison to mechanically driven nails, there were reports of isolated cases of shortening after the planned distraction length was achieved, motor stop, and superficial infections surrounding the implanted subcutaneous receiver of the nail.<sup>36</sup>

### Magnetic Nails

The latest evolution in lengthening nails was inspired from the magnetically controlled growing rods used successfully for the surgical correction of pediatric scoliosis.<sup>37–39</sup> The ability to achieve compression with these nails allows an alternate cycle of distraction-compression (accordion manoeuvre), which is known to accelerate bone regeneration.<sup>40</sup> Two examples of these nails are the Phoenix nail (Phoenix Medical, France) and the PRECICE nail (Ellipse Tech., Irvine, USA). Problems handling the magnet and limitations of its use with excessive soft tissue bulk of the limb have been described with the Phoenix nail.<sup>41,42</sup>

A retrospective study by Kirane et al.<sup>43</sup> on 24 PRECICE nails revealed an accuracy of 96% and precision of 86% with only one implant failure caused by a non-functional distraction mechanism. Another case series by Schiedel et al.<sup>44</sup> demonstrated average lengthening desired was 38 mm and average lengthening obtained was 37 mm in 24 PRECICE nails with two nail breakages.

Since its introduction in 2011, excellent results for the PRECICE nail have been reported and published in over 250 cases. The results demonstrate that the PRECICE nail has less pain and lower complication rates than external fixation methods or previous implantable nail systems. In a study by Lee et al.,<sup>45</sup> overall rate of device-related complications was 74.3% in the ISKD group and 17.6% in the PRECICE 1 group. Moreover, the rate of non-device-related complications were significantly less in the PRECICE group. These results were supported by Hammouda et al.<sup>46</sup> in his case series with 2.2-year follow-up duration.

However, weak distraction force to resist a dense regenerate bone or nail breakage at the modular portion has been reported, and this led to development of the second generation.<sup>47</sup> PRECICE 2 was produced with improved mechanical strength and stability

compared to its predecessor. These improvements have been associated with a decrease in surface degradation with less visible markings, both macroscopically and microscopically.<sup>48</sup> In a retrospective study by Lee et al.<sup>45</sup> PRECICE 2 no longer suffered from nail fractures or weak distraction force. However, an issue in some cases has been failure of rotational stability that resulted in additional surgery.

## NOVEL USES OF LENGTHENING NAILS

### Correction of Malunion

In our institution, patients who have a malunion with leg length discrepancy undergo a corrective osteotomy, acute deformity correction, and insertion of lengthening nail. Depending on the complexity of the deformity either a uniplanar external fixator or TSF is applied temporarily intraoperatively to accurately correct the malunion and hold the correction until the lengthening nail is inserted.<sup>49</sup>

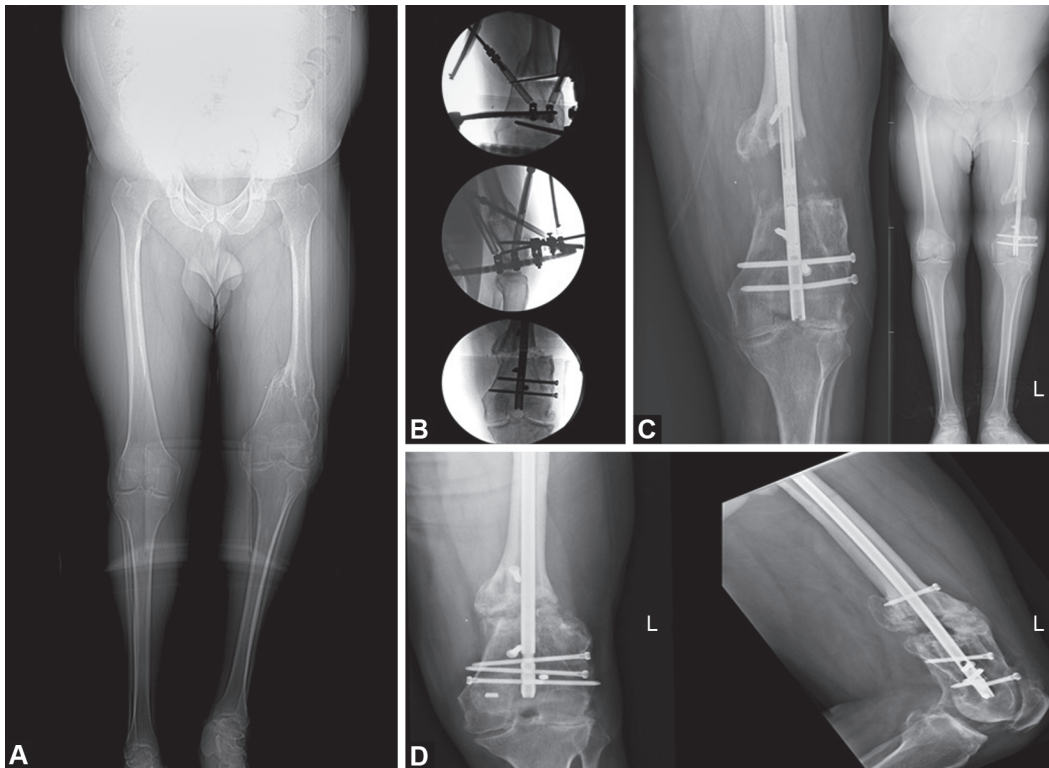
We present two cases in which the lengthening nail has been used in malunion correction. First is a 67-year-old male with a malunited left distal femur as a result of a supracondylar femoral osteotomy as a teenager (Fig. 1). The deformity was 20° of external rotation, 5° of Varus and apex anterior angulation, 2.5 cm medial translation, 4 cm of shortening, and 15° fixed flexion deformity of the left knee. A computer hexapod-assisted orthopaedic surgery (CHAOS) was used in this case owing to the complexity of the deformity to allow accurate correction. A TSF was applied intraoperatively to allow for accurate correction of the rotational deformity, after which, a retrograde precise femoral lengthening nail was applied and the TSF removed after insertion of the nail together with blocking screws. The lengthening index for the patient was 17 days for 1 cm of lengthening and total duration of treatment was 7 months. The nail was eventually exchanged for a conventional static femoral nail to support the union (Fig. 1). Final radiographs show satisfactory alignment of the limb with complete correction of deformity and consolidation of the regenerate. At final follow-up, the deformity site was completely clinically united, and range of motion of the left knee was between 15 and 90° of flexion.

Another example is a 68-year-old male patient who presented with a right tibial malunion with 22° Varus deformity plus 5 cm of shortening. The deformity was acutely corrected using valgus osteotomy and lengthened using a nail (Fig. 2). The nail was finally exchanged for a conventional fixed tibial nail. Follow-up radiographs after 12 months show correction of the deformity and solid union of the regenerate bone.

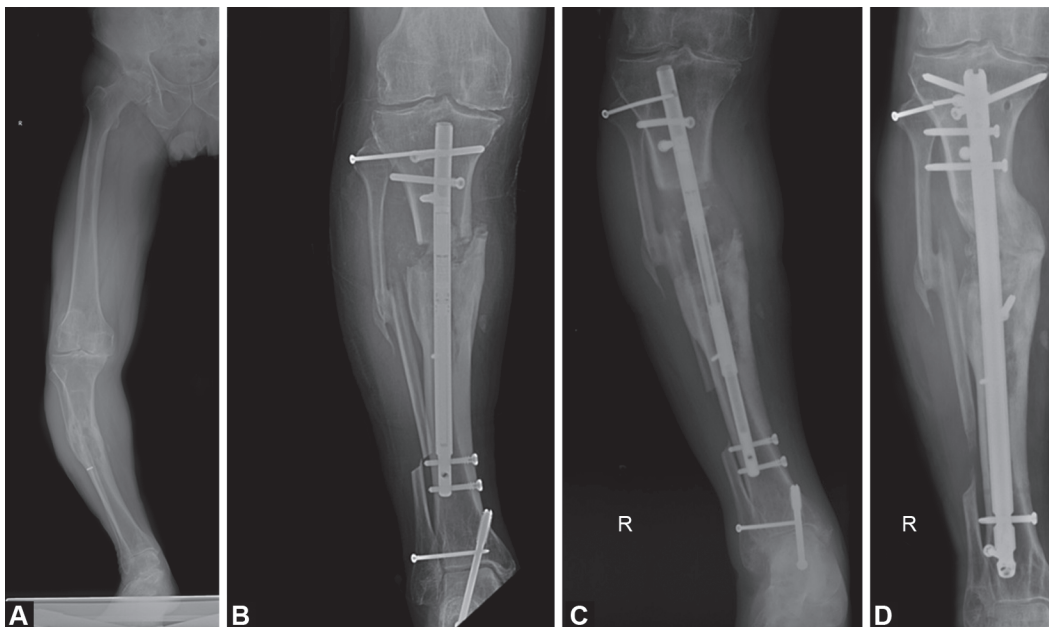
### Treatment of Non-union

We present here two cases where a long-standing oligotrophic non-union was successfully managed with a lengthening nail simply by closed distraction of the non-union and without the use of bone graft or refreshing the non-union site. We believe that the reaming effect of intramedullary nails along with the distraction induced strain of the peri-fracture tissues is enough for induction of union. This was demonstrated previously by Mahomed et al.,<sup>50</sup> where out of the 33 non-union cases, 29 united with closed distraction only using a TSF and without bone grafting.

First is a 66-year-old male patient presenting with a 4-year history of a non-united right tibia. The patient sustained a complex open fracture right tibia with a resultant massive segmental bone defect after debridement. This was initially managed with extensive soft tissue reconstruction with proximal-to-distal bone transport



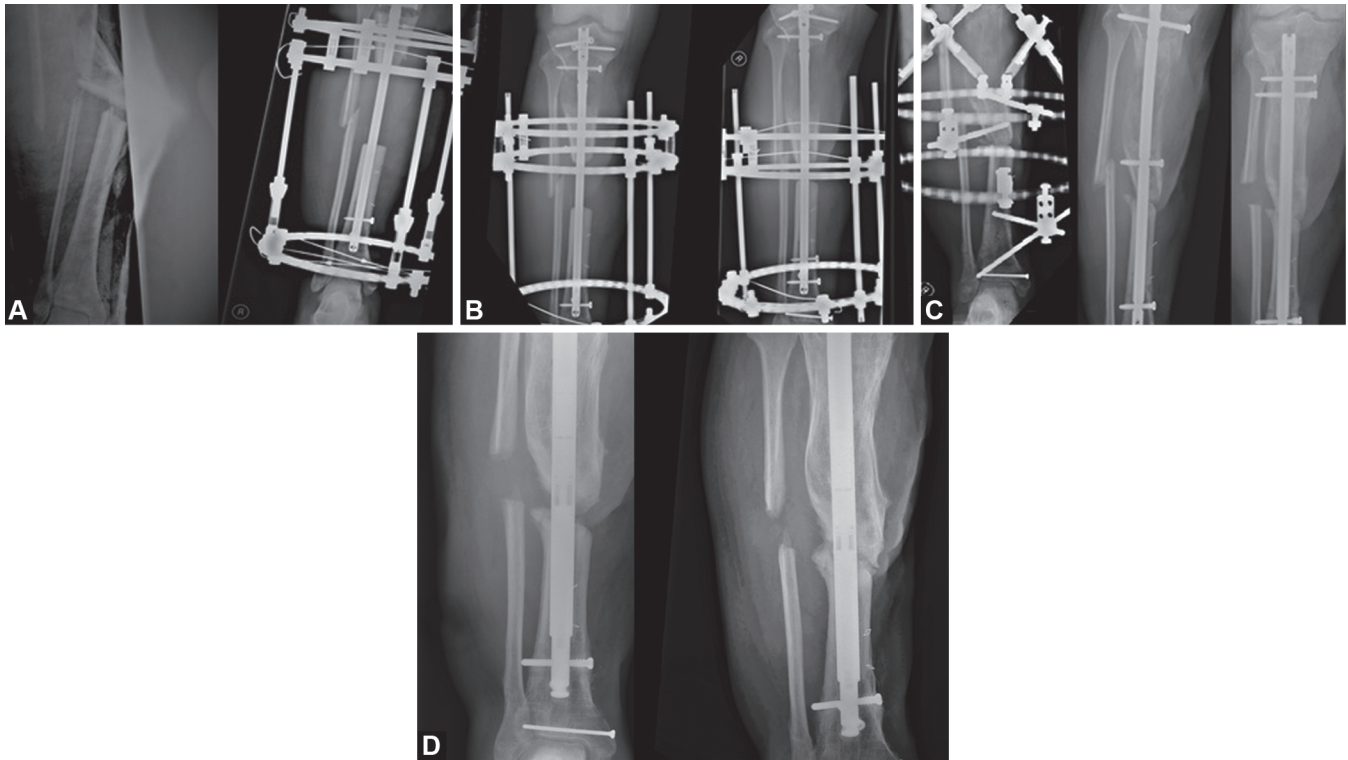
**Figs 1A to D:** (A) Radiograph showing the complex deformity in the left distal femur; (B) Intraoperative radiographs showing the use of temporary Taylor spatial frame to correct the deformity followed by lengthening nail as part of computer hexapod-assisted orthopaedic surgery; (C) Distraction and restoration of length using a lengthening nail; (D) Final anteroposterior and lateral radiographs showing solid consolidation and exchange of lengthening nail with a fixed nail



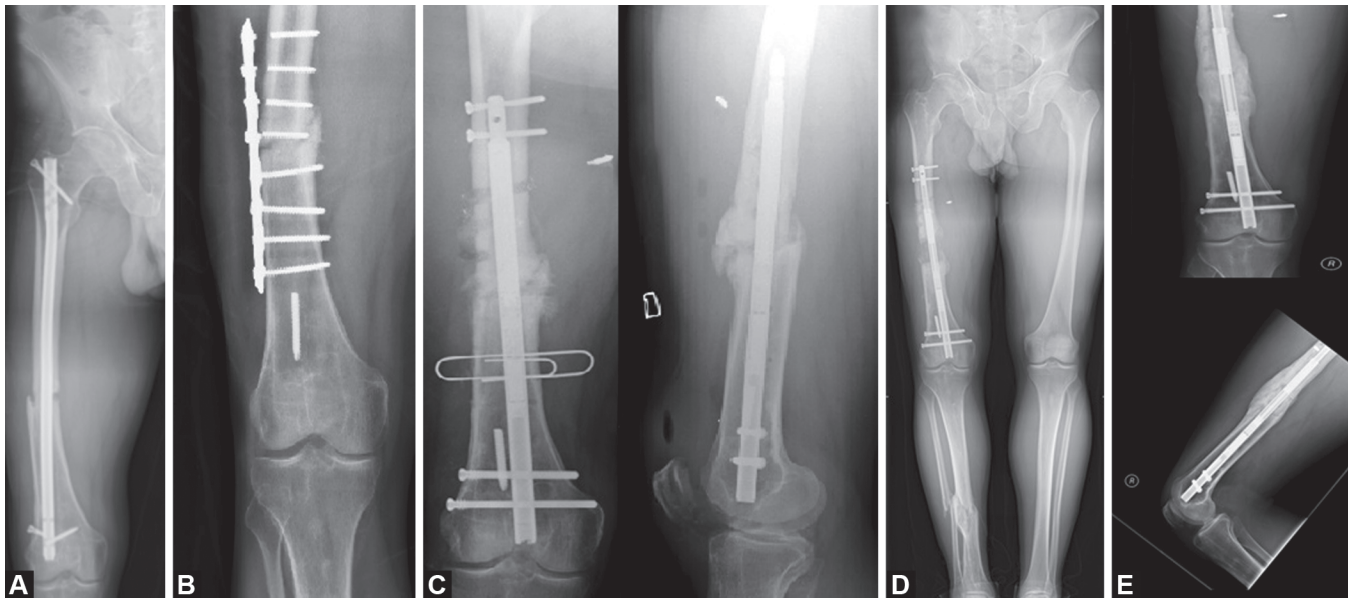
**Figs 2A to D:** (A) Radiograph showing the deformed right tibia; (B and C) Subsequent application and lengthening using lengthening nail; (D) Final radiograph showing solid union of the regenerate and exchange of the lengthening nail with a conventional nail

over an intramedullary nail using an Ilizarov frame (Fig. 3). The intramedullary nail both guided the transport and helped maintain alignment. Unfortunately, the docking site never united while using the Ilizarov frame and a pin site track infection mandated removal of the entire frame and the nail. Infection of the docking site was ruled out. Later on, attempts to achieve solid union at the docking

site first using a TSF, a fixed intramedullary nail in compression and finally an exchange nailing along with fibular osteotomy were all not successful. A lengthening nail was finally utilized to accordion the non-union site, and eventually consolidation of the docking site was achieved (Fig. 3). In a case series presented by Fragomen et al.,<sup>51</sup> it was found that applying only compression of the tibial non-union



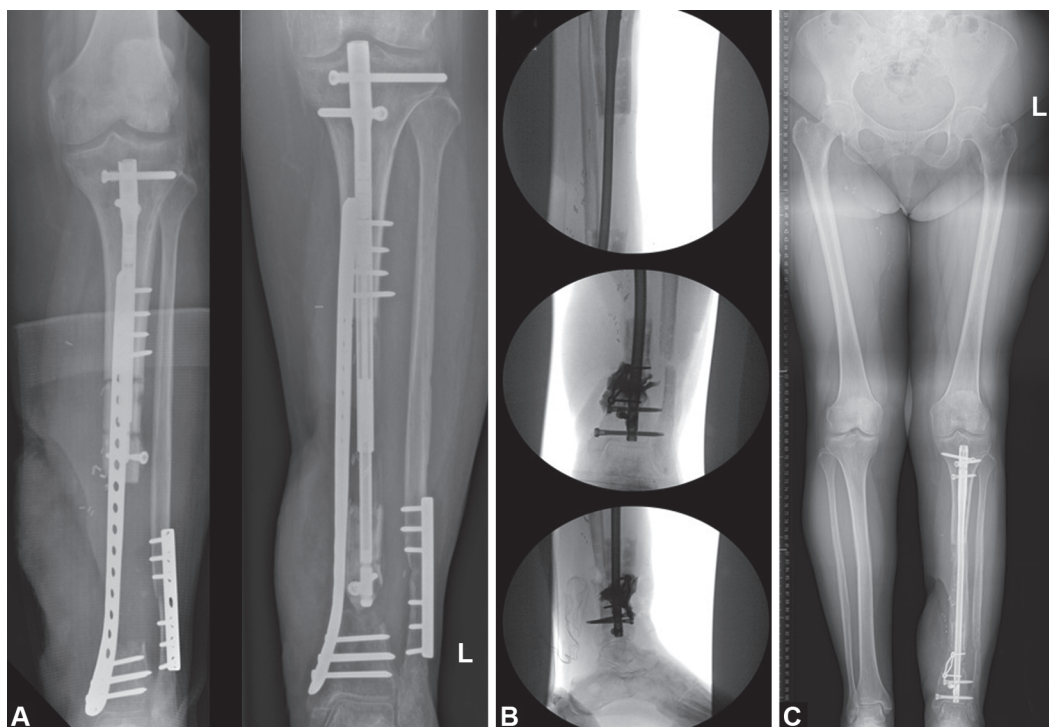
**Figs 3A to D:** (A) Radiographs showing the initial injury of the right tibia and management by bone transport over a tibial nail; (B) Radiographs showing successful regenerate formation and bone transport over an intramedullary nail however with non-union of the docking site; (C) Radiographs showing different trials to induced union at the docking site first by using Taylor spatial frame then a conventional nail then exchange nailing; (D) Final radiographs showing the distraction of the docking site using a lengthening nail then compression to induce union (accordion manoeuvre)



**Figs 4A to E:** (A and B) Radiographs showing non-union of the femur using both an intramedullary nail then a plate; (C and D) Removal of the plate and application of a lengthening nail then lengthening as shown; (E) Final radiographs showing restoration of length and full consolidation at the non-union site

site using a magnetic intramedullary compression nail resulted in successful union but was not as reliable in the proximal metaphyseal region due to resultant deformation forces. It will be interesting to compare both techniques (compression vs accordion technique) in future high-quality studies.

Another case example is a 34-year-old male patient with 3-year history of non-united femur fracture. The femur was shorter than the contralateral one by 4.7 cm when a lengthening nail was applied (Fig. 4). The fracture was distracted to 6 cm then compressed 1 cm to induce union. Lengthening index was 14 days per cm and



**Figs 5A to C:** (A) Radiographs showing the use of the bone transport nail augmented by a side plate; (B and C) Final radiographs showing final application of conventional intramedullary nail after removal of the bone transport nail and the plate. Good regenerate formation is present and the docking site was refreshed, fixed with a hook plate and filled with bone graft substitute

final desired length was fully achieved. Final radiographs reveal complete solid union at the fracture site.

### Bone Transport

We recently used a novel technique, plate-assisted bone segment transport (PABST), to reconstruct a 12 cm defect using a spanning plate and a short lengthening nail. To our best knowledge, this is first case report on the use of the PABST technique in such a long bone defect. The only reported case report utilizing lengthening nails had a bone defect of 4.2 cm compared to a 12 cm in our case presentation.<sup>52</sup>

This is a case of a 52-year-old female with an open fracture grade 3B of the left distal tibia and a resultant 6 cm bone defect after debridement (Fig. 5). The patient underwent removal of the external fixator frame and application of a TSF along with coverage of the skin defect using a fascio-cutaneous flap and split thickness skin grafting. Unfortunately, bone transport was never started in the TSF due to local flap complications. After soft tissue and further bony debridement, the patient was left with a 12 cm bony defect, and PABST technique was performed (Fig. 5). The transport was 3 times a day totaling a length of 0.6 mm per day, and the patient reached final length after 4 months. After the completion of the bone transport, the lengthening nail was exchanged to a conventional nail. The docking site was fixed using a two-hole plate and filled with bone graft substitute. The 12-month follow-up radiographs demonstrate mineralization of the regenerated bone (Fig. 5).

### CONCLUSION

Historically, circular frames have been the gold standard for managing bony defects, malunion, and non-union with leg length

discrepancies. We have demonstrated four cases using lengthening nails, two for malunion and two for non-union including the first report in the literature of PABST for treatment of non-union as well as being the largest defect treated. With the significant advancement of intramedullary lengthening devices with lower complications rates and higher patient satisfaction, over the need for external fixation will be decreased.

### COMPLIANCE WITH ETHICAL STANDARDS

All procedures performed were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

### Ethical Approval

The Research Ethics Committee has confirmed that no ethical approval is required for this study.

### Consent to Participate

All patients in this study gave an informed consent for participation.

### Consent for Publication

All patients and authors gave an informed consent for publication purposes of this article.

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