Hypothesis

Treatment of infective non-union of diaphyseal fractures with Ilizarov external fixation

SK Venkatesh Gupta*, CVS Govindappa, M Rakesh Reddy

Abstract

Introduction
Infection, despite its inflammatory general increase in surrounding blood supply, also leaves large areas of fracture ends dead and sclerotic. It is very difficult to obtain union when coexisting problems, such as deformity, infection and limb shortening is associated. There are many methods available in the management of infected non-union of diaphyseal bones and all protocols have variable rates of success and failures. Most of them are limited in their abilities to re-establish extremity length, correction of deformity, eradicating infection and early functional rehabilitation of the limb during treatment. External fixation in septic environment appears to be the standard treatment for limb stabilisation. Ilizarov and co-workers from Kurgan, Siberia, USSR have employed a new biological technique and different system of ring external fixation with a principle ‘Infection fires in the flames of regeneration’ and could achieve bone union with correction of pre-existing deformities and eradicating infection. The aim of this study was to discuss the treatment of infective non-union of diaphyseal fractures with Ilizarov external fixation.

Materials and Methods
This work is a prospective study comprising of 40 cases of diaphyseal non-union of long bones including patients of age group 21–52 years of both sexes. Monofocal osteosynthesis was done in 27 cases and bifocal in 13 patients.

Results
Average duration of Ilizarov treatment was 10.7 months and average hospital stay was 51 days. Average length of bone regeneration was 3.8 cm (2.2–7 cm).

Conclusion
Ilizarov ring fixator is an excellent treatment modality in the management of non-union and infected non-union of long bones with bone defect, which simultaneously addresses bone union, eradication of infection, correction of deformities, limb length achievement and limb function.

Introduction
Non-union of fracture of long bones is a state in which all the healing processes have come to a halt as judged by clinical roentgen graphic evidence, beyond the speculated period of healing for a particular bone due to mechanical or biologic failure, with a gap being filled with the fibrous or dense fibro-cartilaginous tissue, usually requiring a change in treatment1. Nowadays open fractures with infection perhaps are the most common causes of non-union. Infection after open reduction and internal fixation is a common scenario in India. Infection per-se does not cause non-union as infection healing has been shown to continue independently of the associated infectious process2.

Infection besides inflammatory reaction, also leaves large areas of fracture ends dead and sclerotic. Butterfly and other fragments become equestrian, isolated and devitalised by pus and infectious granulation tissue, which makes fracture healing difficult, if not impossible. Infectious granulation tissue also causes osteolysis, giving rise to gaps that invite non-union. When osteolysis occurs around implants, they loosen, leading to motion, instability and non-union. Thus, infection causes non-union earlier than non-infected patients3.

Inadequate fixation of fracture by plate or nail, segmental fractures, comminuted fractures by severe trauma, intact fibula or early union of fibula distraction by either traction, plate or screws, treatment by ill advised open reduction, soft tissue injury in open or closed fractures, soft tissue interposition in between fracture ends are the common cause of non-union4.

To obtain union, eradication of infection, maintenance of limb length and function of extremity during treatment often requires courageous measures with increasing risk of failure or not often amputation. Standard principles of debridement and antibiotic therapy alone may result in an acceptable cure rate for less severe type of infection. Resistant infections usually require a more radical debridement of septic bone and soft tissue in addition to application of stable fixation to enhance soft tissue and bone healing5.

It is very difficult to obtain union when coexisting problems like deformity, infection and limb shortening is associated. There are many methods available in the management of above said problems and all protocols have variable rates of success and failures. Most of them are limited in their abilities to re-establish extremity length, correction of deformity, eradicating infection and early functional rehabilitation of the limb during treatment6.

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In the presence of active infection and segmental bone loss with poor soft tissue coverage, internal osteosynthesis indisputably present a high risk of recurrent infection. Bone grafting with available modalities pose problems in maintaining limb length, correcting deformity and beyond all requires prolonged immobilisation resulting in severe regional osteoporosis thus precluding union. Vascular zed fibular graft requires micro-vascular repair by high-skilled personnel even though the results comparable with other non-vascular bone grafting techniques due to failure of graft. External fixation provides a minimal amount of foreign body material and if properly constructed, provides sufficient stability to the extremity. Therefore, external fixation in septic environment appears to be the standard treatment for limb stabilisation.

But Ilizarov and co-workers from Kurgan, Siberia, USSR have employed a new biological technique and different system of ring external fixation to achieve: (1) bone union, (2) correct pre-existing deformities, (3) eradicate infection, (4) re-establish limb length, (5) eliminates bone defects without bone graft, (6) maintain articular function and (7) permitting weight bearing during treatment. This study evaluates the role of Ilizarov fixation in infective non-union of diaphyseal fractures.

Advantages of Ilizarov ring fixator include: (1) elastic type external ring fixator, which allows micromotions in conductive to fracture healing and regenerate, (2) forces acting in circular fixator and multi-planar Ilizarov's fixator distributes stresses move evenly across the fracture or corticotomy sites and therefore three-dimensional correction is possible and axial compression-distraction, angular and translational correction are also possible using a gradual mechanical technique, (3) allow immediate weight bearing and function, (4) can be used in bones with osteoporosis and (5) Ilizarov fixator can work in septic environment permitting correction of limb length discrepancy and immediate weight bearing during treatment.

Disadvantages of Ilizarov ring fixator include: (1) long learning curve, (2) dependence on personal creativity of surgeons, (3) more labour-consuming assembly compared with unilateral frame, (4) multiple outpatient visit necessary, (5) decreased quality of life while fixator is in place, (6) problems with non-compliant patients and (7) high incidence of pin-site infection; contracture of adjacent joints caused by transfixation of muscles.

### Tension stress phenomena of Ilizarov

The law of tension stress was elucidated by Prof. Ilizarov and it states that when living tissues are subjected to graduated planar distraction forces in the presence of intact function and vascularity, and the bone is subjected to a low energy osteotomy, new bone and all other tissues in the limb are formed by a process of Neo Histogenesis.

If the tissue is stimulated by elastic micromotion, the nerve impulses help control the passage of electrically charged ions through the cells activating the ion channels. The exact mechanism of the elastic micromotion cellular development interaction is not clear. The activated ion channels in turn results in rapid mitosis during bone distraction and thus generates more rapid callus formation and maturation.

The methods of Ilizarov technique require an understating of how mechanical forces are used in the following two separate biological processes.

1. Distraction osteogenesis
2. Transformation osteogenesis.

### Distraction osteogenesis

It is the production of new bone formation between vascular bone surfaces which are separated through gradual distraction. Distraction is most commonly achieved through a corticotomy at a rate of 1 mm per day, divided into 0.25 mm increments 4 times a day, following 7 day latency period.

Corticotomy is a low-energy osteotomy that is performed using a corticotomy to cut only the cortical surface, thus preserving the medullary canal and periosteum following corticotomy; the initial healing response is allowed to bridge the cut bone surface before distraction is initiated. This period of time is called latency. The rate and rhythm of distraction are critical in formation of new bone (Figure 1).

### Transformation osteogenesis

It is the conversion of non-osseous tissue, such as fibrocartilage in non-unions, synovial cavities in pseudarthrosis into normal bone. This is accomplished by combined compression and distraction forces at times augmented by corticotomy.

### Histology of distraction osteogenesis

Investigated based on biopsy specimens and bone sections.

First week: During first week of distraction the central zone of relatively avascular fibrous tissue bridge the 6–7 mm corticotomy gap, this is known as fibrous inter zone (FIZ).

At the same time spiral-shaped cells which resemble fibroblast are loosely interposed between collagen bundles. Osteoid and osteoblasts are not present radiologically, and the radiolucent zone was seen in between the corticotomy surface.

Second week: Clusters of osteoblast appear on each side of FIZ adjacent to the vascular sinuses and collagen bundles mixed with an osteoid-like matrix. As these primary bone spicules they gradually enlarge by circumferential apposition of collagen and osteoid. The osteoblastic cells become enveloped within the matrix.

Later in the second week osteoids become mineralised, these bones

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spicules are known as primary mineralisation front (PMF)\textsuperscript{16}. They extend from each corticotomy surface towards the central fibrous interzone.

Third week: Mineralisation continues and as the gap increases, bridging is formed by elongation of the new bony spicules running in the direction of distraction. The tips of the spicules begin at a diameter of 7–10 µm and expand up to 150 µm near the corticotomy surface. This zone is referred to as micro-column formation (MCF)\textsuperscript{16,17}. At the end distraction the FIZ ossifies and the micro-column formation unifies completely bridging the gap.

Distraction osteogenesis has been referred to as growth plate in sense of bone regeneration. However histologically, it is intra membranous ossification in its purest form.

\section*{Materials and Methods}

This work conforms to the values laid down in the declaration of Helsinki (1964). The protocol of this study has been approved by the relevant ethical committee related to the institution in which it was performed. All subjects gave full informed consent to participate in this study.

A prospective study comprising 40 cases was done at the Department of Orthopaedics and Traumatology, Mamata Medical College, Khammam. The diaphyseal non-union of long bones included age groups 21–52 years including both sexes. The major group consists of open fractures due to road traffic accidents. Most of the cases had been treated with 2–3 previous surgical procedures. Non-union was classified based on Paley’s non-union classification\textsuperscript{17}. The duration of non-union before Ilizarov treatment ranged 6–18 months. Patients were evaluated regularly with x-rays and functional outcome was assessed by the Paley et al. criteria. The present study, done with Ilizarov principles, consists of 40 patients. Out of which 30 patients – Tibia, 8 patients – Femur, 02 – Humerus were included in the study.

\section*{Results}

Mean age of the study group was 37.3 years (21–52 years) and included 5 females and 35 males. Monofocal osteosynthesis was done in 27 cases and bifocal in 13 patients. Average duration of Ilizarov treatment was 10.7 months and average hospital stay was 51 days. Average length of bone regeneration was 3.8 cm (2.2–7 cm). Table 1 shows types of non-union cases treated as classified by Paley’s classification.

There was a pin tract infection in 18 cases that resolved gradually. Transient pain at pin site was seen in 24 patients. Transient oedema of the limb was seen in eight cases. No cases of wire cut through or fixator failure was noted. Ankle stiffness was seen in five cases and knee stiffness in three cases. Table 2 shows bone and functional results of the study group as compared with other studies (Figures 2 and 3).

\section*{Discussion}

Non-union of long bones with associated deformity, persistent infection, loss of bone and soft tissue contracture has always been a
Table 1 Distribution of cases

<table>
<thead>
<tr>
<th>Paley’s type of non-union treated</th>
<th>No. of cases</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>A2</td>
<td>11</td>
<td>27.5</td>
</tr>
<tr>
<td>B1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B2</td>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td>B3</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>17</td>
<td>42.5</td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 2 Bone and functional results of the study group as compared with other studies

<table>
<thead>
<tr>
<th></th>
<th>Paley et al.18,19 (%)</th>
<th>Farmanullah et al.20 (%)</th>
<th>Sahu et al.21 (%)</th>
<th>Present study (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone results</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excellent</td>
<td>72</td>
<td>58.89</td>
<td>78.57</td>
<td>77.50</td>
</tr>
<tr>
<td>Good</td>
<td>20</td>
<td>20.68</td>
<td>14.29</td>
<td>17.50</td>
</tr>
<tr>
<td>Fair</td>
<td>8</td>
<td>13.79</td>
<td>7.14</td>
<td>5</td>
</tr>
<tr>
<td>Poor</td>
<td>0</td>
<td>20.68</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Functional results</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excellent</td>
<td>64</td>
<td>56.89</td>
<td>n/a</td>
<td>75</td>
</tr>
<tr>
<td>Good</td>
<td>28</td>
<td>31.05</td>
<td>n/a</td>
<td>15</td>
</tr>
<tr>
<td>Fair</td>
<td>4</td>
<td>6.89</td>
<td>n/a</td>
<td>10</td>
</tr>
<tr>
<td>Poor</td>
<td>4</td>
<td>5.17</td>
<td>n/a</td>
<td>0</td>
</tr>
</tbody>
</table>

Careful preoperative evaluation with radiographs in understanding the anatomy of non-union enabled to reduce the operation time.

Patients followed up at regular intervals of 2–3 weeks and the problems such as pin site infection and pain were rectified early.

Union rates reported in hypertrophic aseptic non-unions are 87.8% (Boyd H.B, Lipinski)30, 72.1% (Zumbrunnen)31 and 85% (Gershuni DH, and Pinskerk)32 for closed bone grafting procedures.

Union rates of non-unions were 88% with internal fixation without bone grafting (Rosen)33 and 78.8% for direct electrical stimulation (Brighton et al)34. In all these patients healing time averaged 6–8 months.

Cierny compared conventional and Ilizarov methodologies in 44 patients with segmental defects of tibia, divided 21 patients as Group I, managed with Ilizarov and 23 patients as Group II managed with massive cancellous bone grafts, and tissue transfers concluded that there were major complication rates of 60% compared with 33% of Ilizarov treatment26.

In all the above studies, it was observed that the great advantages of Ilizarov technique is the ability of the patient to ambulate and weight bear from the immediate post-operative period, very less chances of fixator failure, simultaneous treatment of all the chronic problems of non-union and the bone regeneration is superior to cancellous bone graft. Soft tissue coverage will not be a problem at the non-union site, adjustment of alignment and length can be done even after surgery.

The disadvantages with this are mainly patient intolerance to the bulky external frame, prolonged treatment time, transfixation of muscles by the percutaneous wires, steep learning curve, patient participation challenge to orthopaedic surgeons. The problem of limb length discrepancy may be with an extensive operative procedure and a technical procedure. That does not allow early mobilisation and weight bearing, thus it may be associated with disuse osteoporosis, soft tissue dystrophy and persistent infection in the presence of implants Weiland et al22, studied 64 cases of infected non-union of long bones with 21 years of follow-up study.

Better results have been reported with staged reconstruction with either immobilisation of the limb in a plaster cast or with external fixation and with bone grafting. Open cancellous bone grafts (Papineau) have been used successfully to fill the bone defects23.

Most of the treatment methods that are highly successful at obtaining union cannot address the above said problems at the same time24.

These treatment methods are destined for failure in infected non-unions unless adequate debridement of the infected area and reconstruction of any discontinuity of the bone is not achieved25.

The Ilizarov frame construct is very resistant to torsion and bending forces but adaptable to axial loading. It allows significantly more micromotion at the fracture site during axial compression than other available fixators. This is an uncommon characteristic that isolates the Ilizarov from the rest26–29.

Hypothesis
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Figure 2: Case of excellent functional result after bifocal osteoid synthesis by compression distraction osteogenesis.

Conclusion

Ilizarov ring fixator is an excellent treatment modality in the management of non-union and infected non-union of long bones with bone defect, which simultaneously addresses bone union, eradication of infection, correction of deformities, limb length achievement and limb function. For optimal results, the treatment needs to be individualised for the needs of the patient by the treating surgeon.

Abbreviations list

FIZ, fibrous inter zone; MCF, micro-column formation; PMF, primary mineralisation front.

References
