
Histologic Features of the Regenerate

Histology, Early Phases

Under the microscope, the tissue that forms in the widening distraction gap under the influence of steady distraction has some interesting features. In the early phases of distraction osteogenesis, the widening gap contains poorly differentiated connective tissue. This substance slowly organizes into small cones of newly forming bone attached to the fragment ends, separated by a fibrocartilaginous layer. With additional time, distraction, and stability, the entire zone fills with osseous tissue, often with a band of cartilaginous tissue zigzagging across the middle (Fig. 2.1).

Histology, Vascularization

In the early phases of distraction osteogenesis, parallel longitudinal columns of fibrous tissue form. When cut in cross section and viewed under a microscope, these columns have the appearance of honeycombs, whereas when cut longitudinally, they resemble the striations in a stalk of celery [1, 2] (Fig. 2.2).

This new tissue is highly vascularized, with newly formed blood vessels occupying the spaces between the longitudinal fibers.

At the electron microscopic level, the newly forming fibrous tissue, subjected to continuous traction by the elongating mechanism, contains stretched out mitochondria and elongated endoplasmic reticulum (Fig. 2.3).

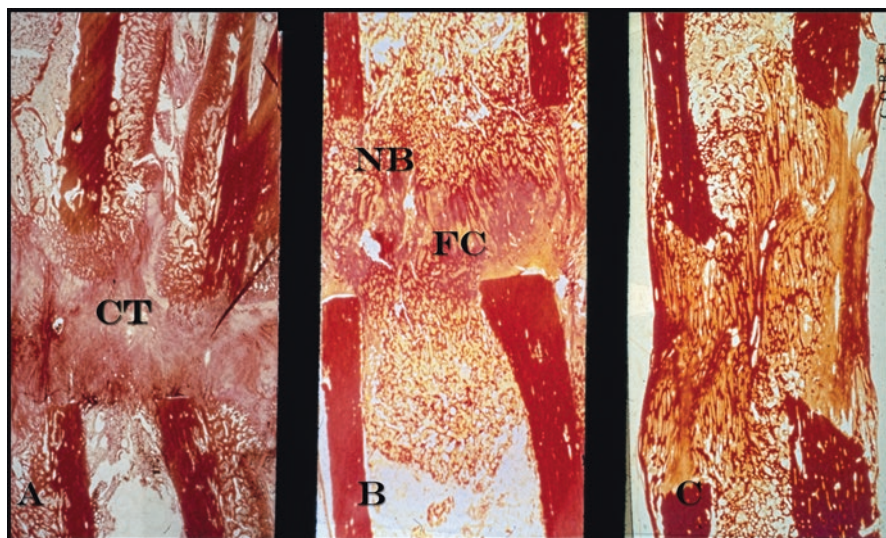


Fig. 2.1 Formation of the bone in a widening distraction zone. (a) Initially the zone is filled with connective tissue (CT). (b) Next, new osseous tissue (NB) forms at the fragment ends, while fibrocartilage (FC) forms in the middle region. (c) Eventually, the bone, oriented longitudinally, consolidates the distraction zone. Reprinted from *Transosseous Osteosynthesis*, “The Tension-Stress Effect on the Genesis and Growth of Tissues,” 1992, pp. 137–255, G. A. Ilizarov, Copyright Springer-Verlag Berlin Heidelberg. With permission of Springer

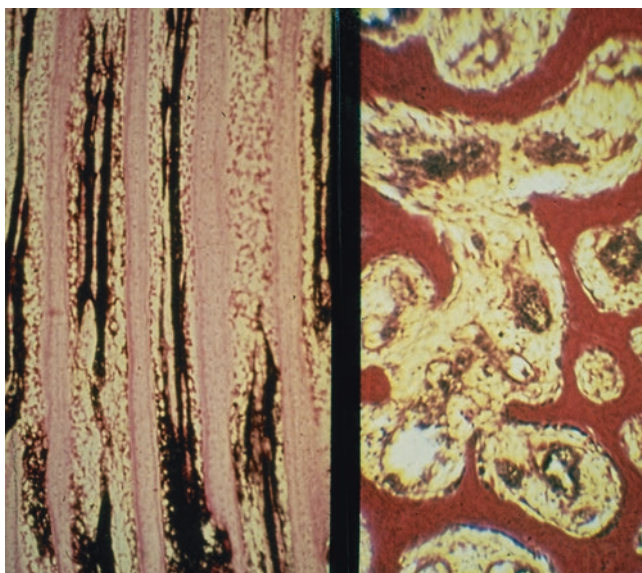
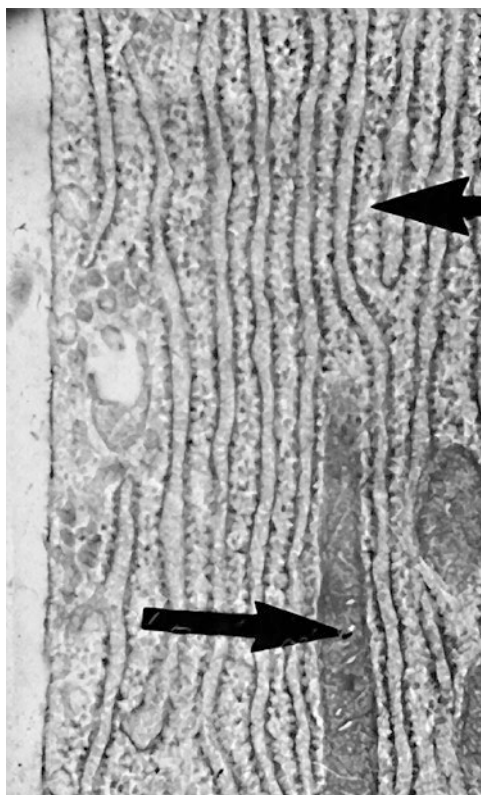


Fig. 2.2 Longitudinal (left) and transverse (right) section of newly formed regenerate bone with India ink stain. Blood vessels show as black. Note the vertical striations in the longitudinal section and the honeycomb appearance of the transverse section. Reprinted from *Transosseous Osteosynthesis*, “The Tension-Stress Effect on the Genesis and Growth of Tissues,” 1992, pp. 137–255, G. A. Ilizarov, Copyright Springer-Verlag Berlin Heidelberg. With permission of Springer

Fig. 2.3 Electron micrograph of a fibrocyte in the distraction zone. Notice the elongated mitochondria (*lower arrow*) and the stretched-out endoplasmic reticulum. 22,000 \times . Reprinted from *Transosseous Osteosynthesis*, “The Tension-Stress Effect on the Genesis and Growth of Tissues,” 1992, pp. 137–255, G. A. Ilizarov, Copyright Springer-Verlag Berlin Heidelberg. With permission of Springer



The Fibrous Interzone

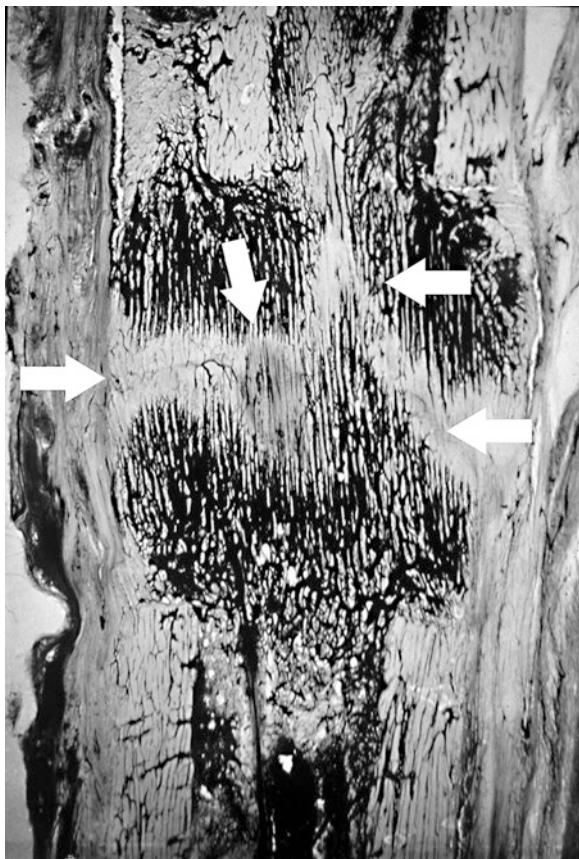
When external fixation is used to create the distraction regenerate, a dark zigzag line often appears traversing the center of the distraction gap [3, 4]. This region is called “the interzone.” It is perceived as a kind of growth plate of the distraction regenerate. The interzone would naturally be hard to see when an intramedullary device occupies the middle of the bone (Fig. 2.4).

As the white lines get denser and thicker, they eventually cross the interzone, indicating that ossification has proceeded along the entire regenerate. This usually does not occur until the distraction phase of the process has been completed.

Maturation Phases

The fibrous tissue in the elongating distraction zone consists primarily of collagen. Gradually, tiny calcium hydroxyapatite crystals are deposited within the collagen fibers, stiffening them. Such collagen fibers with embedded calcium hydroxyapatite

Fig. 2.4 India ink preparation showing the fibrous interzone (white arrows) zigzagging across the middle of the regenerate region. Reprinted from *Transosseous Osteosynthesis*, “The Tension-Stress Effect on the Genesis and Growth of Tissues,” 1992, pp. 137–255, G. A. Ilizarov, Copyright Springer-Verlag Berlin Heidelberg. With permission of Springer



crystals are the basic ingredients of bone. The calcium hydroxyapatite crystals, because of their density, absorb x-ray beams. These absorbed beams never darken an x-ray film, so they appear white when the film is viewed on a translucent view box.

Thus, increasing maturation of the regenerate bone is characterized by progressive lightening of the x-ray image between the distracted bone ends. Under ideal conditions, the longitudinal orientation of the maturing columns of bone is visible on x-ray studies, seen as thin white bands separated by darker, more radiolucent bands. The white bands, appearing on x-ray studies as though painted against a dark surface with a paintbrush, are most mature at the bone ends and tend to fade toward darkness at the center of the regenerate (Fig. 2.5).

Ossification

Ilizarov believed that he had discovered a new kind of bone formation, differing from both intramembranous ossification (that occurs underneath the periosteum in a growing child) and endochondral ossification (that occurs at both the growth plate

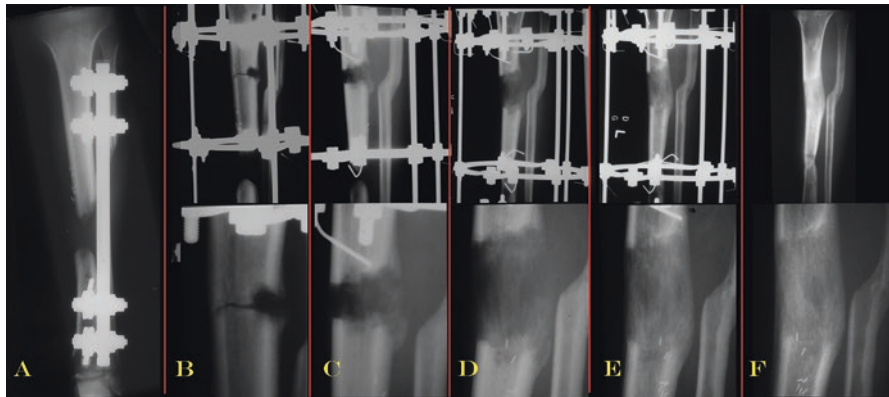


Fig. 2.5 (a) Segmental defect of the tibia, stabilized with a monolateral fixator. (b–f) Placement into a ring fixator and osteotomy through pinhole showing progressive phases of distraction zone elongation and maturation (*top* = whole bone; *bottom* = close-up of regenerate). (f) Final image with frame removed. Copyright 2016 Zeeca Publishing Co

of a child and during the process of healing of a fresh fracture treated in a cast). In the latter situation, the blood clot created from the ends of the broken bones first turns into cartilage, which, in turn, matures into bone.

The Ring of Ranvier

Aronson et al. [5], at Little Rock Children’s Hospital, has shown with histological studies that regenerate bone forming in a widening distraction zone is indistinguishable from bone that forms in a growing child at the circumferential outer corner of a growth plate, in a zone called “the Ring of Ranvier.” In this region, intramembranous bone forms on the undersurface of the periosteum which is simultaneously being stretched by the elongating power of the growth plate. The combination of lengthening and widening of bone characteristic of childhood creates osseous tissue in longitudinal columns with the same appearance as Ilizarov’s distraction regenerate.

Thus, Ilizarov’s method reactivates a quiescent means of bone formation originally designed by nature for a growing child.

Factors Influencing Regenerate Quality

Stability

Ilizarov employed a canine model to explore factors that optimized outcomes. He and his co-workers learned that the best quality of regenerate bone formation occurs when there is excellent rotational and side-bending bone stability in the ring fixator that, nevertheless, allows axial motion in a trampoline effect [6].

Osteotomy/Corticotomy

Likewise, researchers at Ilizarov's institute determined that good-quality bone formation is more likely to occur when there is a "sparing" (gentle) osteotomy of bone to create the distraction gap [6]. Moreover, they learned that protecting the endosteal blood supply by cracking the cortex without crossing the medullary canal (the "corticotomy") also enhanced bone formation in the widening distraction gap [1].

Rate and Rhythm of Distraction

Scientists in Kurgan determined that the best distraction rate is typically 1 mm per day, divided into multiple doses. The more highly fractionated the distraction, the better the quality of the bone [2]. They also learned that it takes at least twice as long for the bone to mature once distraction is complete than it did to elongate the fragments in the first place, with this being the minimum amount of time required for maturation, generally occurring in children. Regenerate maturation in adult bones takes longer, perhaps three or four times longer than the distraction phase time cycle. In cases where the soft tissues surrounding the regenerate region have been injured, maturation can be slow indeed. A region of the limb that had previously been irradiated to treat malignancy may not support maturation of the regenerate at all.

Ilizarov Terminology

Introduction

"Bilocal consecutive distraction-compression osteosynthesis" is Ilizarov's term for the procedure referred to in the Western orthopedic literature as "bone transport"—the filling in of a segmental osseous defect by pulling a bone fragment through the tissues. Ilizarov's terminology for the numerous strategies of osseous reconstruction helps surgeons communicate the conceptual framework for any treatment plan. For this reason, orthopedists using Ilizarov's methods should employ Ilizarov's terminology to clearly describe treatment tactics to knowledgeable colleagues in North America, Europe, and elsewhere in the world. Furthermore, Ilizarov's publications will be more easily understood and enjoyed if readers are familiar with his descriptive terminology.

Ilizarov usually characterizes procedural strategies by four terms, which form the basis of treatment: location, sequence, action, and objective.

Location

The first term describes the number of locations along a bone where osseous manipulations are occurring. For example, if there is simple compression (or distraction)

at only one level, the procedure is referred to as “monolocal.” However, if at one level a segmental defect is being closed while at a second location within the same bone a corticotomy site is being distracted, the strategy is referred to as “bilocal.” Likewise, if two corticotomy sites within a bone are being distracted while a skeletal defect between them is being closed, the technique is referred to as “polylocal.”

Sequence

The second term in the treatment protocol describes the sequence of maneuvers. Thus, therapy can be either “simultaneous” (when different actions are occurring at the same time) or “consecutive” (when one action precedes a second).

Action

The third term defines the actual maneuver (or maneuvers) used to effect the reconstruction. In most cases involving movement of bone fragments, this action may be either “compression,” “distraction,” “compression-distraction,” and “distraction-compression” or (when correcting deformities) “simple opening wedge,” “distractional wedge,” and “translational wedge.” As a rule, the first term describes the first action in a sequence.

Objective

The last term in the description refers to the goal of therapy. Hence, repair of a fracture or non-union would be called “osteosynthesis,” while limb elongation would be referred to as a “lengthening.” Limb elongation by traction on a child’s growth plate is called “traction epiphysiolysis.” Obviously, obliteration of a growth plate by external compression (to treat, e.g., hemihypertrophy) would be “compression epiphysiodesis.”

Summary

In a situation where a simple transverse hypertrophic non-union is compressed in an external skeletal fixator to promote union, the Ilizarov terminology for this treatment strategy would be “monolocal compression osteosynthesis.” A limb lengthening through a single level (without deformity correction) is called “monolocal distraction lengthening.”

When closing a skeletal defect in a bone by transporting an osseous segment through the limb (after performing a corticotomy elsewhere in the bone), the strategy is called “bilocal consecutive distraction-compression osteosynthesis” since the corticotomy site is distracted *before* the defect is compressed. In some situations, a

non-union site is compressed (shortening a limb slightly) at the same time that limb length is restored through a corticotomy elsewhere in the bone. This strategy is called “bilocal simultaneous compression-distraction osteosynthesis.” In oblique hypertrophic non-unions associated with shortening, a single location may be compressed for 2 weeks and then distracted to regain length (new bone forms in the non-union site); such a regimen is called “monolocal consecutive compression-distraction osteosynthesis.”

Certain pathologic bone diseases—such as diffuse chronic osteomyelitis—can be cured (according to Ilizarov) by performing an oblique S-shaped osteotomy through the region, followed by gradual distraction (after the usual latency interval). The new bone, which forms within the distraction gap, can serve as a highly vascularized cancellous bone graft. Since the limb might end up too long if left in the elongated position, the distraction is stopped and the osteotomy gap gradually compressed until the original limb length is restored. This procedure squeezes the newly formed bone into the microabscesses of the osteomyelitic bone. Such a sequence would be referred to as “monolocal consecutive distraction-compression osteosynthesis.”

Conclusion

Surgeons using Ilizarov’s method of treatment—or any modification, for that matter, including intramedullary lengthening—will find it convenient to use Ilizarov’s terminology to express the location, sequence, action, and objectives of a treatment plan employing external skeletal fixation and the movement of bone fragment.

Applications of the Ilizarov Method

The list of applications of Ilizarov’s method has grown considerably since its inception. It now includes:

- Limb lengthening and deformity correction
- Percutaneous treatment of all closed metaphyseal and diaphyseal fractures as well as many epiphyseal fractures
- Repair of extensive defects of bone, nerve, vessel, and soft tissues without the need for grafting and in one operative stage
- Bone thickening for cosmetic and functional reasons
- The percutaneous one-stage treatment of congenital or traumatic pseudarthroses
- Limb lengthening to treat growth retardation through distraction epiphysiolysis or other methods
- The correction of long bone and joint deformities, including resistant and relapsed clubfoot
- The percutaneous elimination of joint contractures
- The treatment of various arthroses through osteotomy and repositioning of the articular surfaces

- Percutaneous joint arthrodesis
- Elongating arthrodesis—a method of fusing major joints without concomitant limb shortening
- The filling in of solitary bone cysts and other such lesions
- The treatment of septic non-unions by the favorable effect of stimulated bone healing on infected bone
- The filling in of osteomyelitis cavities by the gradual collapse of one of the cavity walls
- The lengthening of amputation stumps
- Management of hypoplasia of the mandible and similar conditions
- The ability to overcome certain occlusive vascular diseases without bypass grafting
- Correction of achondroplasia and other forms of dwarfism

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