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PERSPECTIVES

Ilizarov for radiologists

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Many units across the country are now using external fixators and the Ilizarov method to stabilise complex fractures or encourage new bone formation in non-unions or bone-loss situations. The aim of this article is to familiarise the interpreter with the basic principles of the technique, explain some of the terminology and point out the kind of problems we frequently experience and therefore what we are looking for on the seemingly endless stream of check X-rays requested. Hopefully this may make the reporting of these x-rays more enjoyable and maybe avoid the odd particularly unhelpful 'fixator in position as shown' report.

Background

Gavriil Abrimovic Ilizarov was a Russian surgeon posted to Kurgan (Siberia) in the 1950s. He developed a system of external fixation using the basic materials available to hand to cope with the large volume of complex Cold War and industrial injuries occurring at a time when antibiotics and plastic surgery were in short supply. The use of tensioned fine wires supported on rings with adjustable rods enabled him to achieve rigid bony fixation and fracture manipulation without opening closed injuries or having to implant metalware into the zone of injury in open injuries. He noticed that if corrections were made as fractures were healing that this seemed to encourage callus formation and that if this callus was stretched at certain rates then the bones could be lengthened. By the addition of simple hinges and drivers at the appropriate places on the frames, quite complex deformities of bone and soft tissues can be addressed. He performed extensive animal and clinical research but, since it was all in Russian, it was not until the 1970s that Westerners became aware of it and started to adopt these incredible techniques.

Indications
Congenital deformity
Growth plate arrest
Maluinion
Non-union
Open fractures
Combined metaphyseal/diaphyseal fractures
Bone loss fractures
Tumour resection
Osteomyelitis

Basic principles

When healing bone is distracted at a certain rate and supported in the correct mechanical environment then it will keep generating callus for as long as you keep distracting. The Ilizarov frame provides the distraction force and stability but also allows just enough micromotion on weight bearing to promote maturation and remodelling of the newly formed bone. The only limiting factors are adjacent joints and soft tissues so lengthening of up to 15 or 20% of each segment is possible. All tissues will stretch and respond with new cell formation to a certain degree including muscle, skin and tendon but nerve tissue is less tolerant of stretch so care must be taken around

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nerves closely applied to or tethered to bone. It is of particular interest that the scar tissue and cartilage that may have formed between the bone ends in fracture non-unions also respond to this controlled distraction by differentiating and forming bone. The Ilizarov method is thus an extremely powerful technique that can be used to correct angular deformity, lengthen bones, restore bony union and replace lost bone, sometimes all at once! Where a simple uni-planar deformity exists or a straight lengthening is required, a single corticotomy or monofocal technique is used. For longer lengthening, the use of two corticotomies (bifocal) can halve the lengthening time since distraction can occur in two places at once. Bifocal techniques also allow for resection and compression of an infected non-union at one site and re-lengthening of the bone at another site simultaneously. Where there is extensive bone loss a technique called bone transport allows a segment of bone to be pulled across a gap whilst keeping the overall length of the leg constant. This is often used following resections of bone tumours or significant bone-loss fractures.

Ilizarov frame modes
Unifocal
Compression
Distraction
Angular correction
Bifocal
Lengthening
Compression-distraction
Bone transport

Classic verses spatial frames

The majority of limb deformities can be evaluated and broken down into one or two uniplanar angulations. With a sheet of graph paper and a bit of thought it is usually possible to design a frame with a hinge placed at just the right point in relation to the centre of rotation of the angulation (CORA) such that when a driver is placed to act on that hinge, all of the angulation, lengthening and translation can be addressed. This is the art of Ilizarov frame design. Some deformities however are not so easily resolved. Standard Ilizarov frames are a bit clumsy when it comes to correcting rotation and translation at the same time and occasionally the frame design may require placement of a hinge in an awkward place such as beyond the end of the bone or into a joint. More recently, a system using six angled struts arranged in a zigzag pattern between two rings allows corrections to be planned in any plane of motion with the help of a computer programme (Taylor spatial frame). Effectively a ‘virtual hinge’ can be placed wherever you like and corrections to length, alignment and rotation performed all at the same time. It is a very powerful tool but the basic rules of computer programmes apply such that ‘rubbish in will get rubbish out’; you still have to define the deformity accurately and tell the computer precisely what you want it to do. For spatial frames, the radiographs need to be perfectly square to the frame in both AP and lateral views, and magnification markers need to be placed to allow accurate planning of corrections.

Stages of the Ilizarov method

Frame application and corticotomy

Frames are applied under general or regional anaesthesia in the operating theatre (Fig. 1). Under image intensifier control, reference wires are passed at either end of the segment parallel to the adjacent joints. The wires have sharpened tips and are pushed through the skin onto bone and then advanced through the bone with a slow speed drill to avoid too much heat generation. Once through the other side they are then tapped through the rest of the way with a hammer to avoid winding up the soft tissues on the way out. A frame is then constructed to match any deformity in the limb with hinges placed at the pre-planned locations and is mounted on the reference wires. Further wires are passed to stabilise the frame with at least two wires at each ring. The goal is to achieve as large an angle as possible between the wires to help stability but still take care to avoid important neurovascular structures. When frames are applied for deformity correction the bone must first be divided. Ilizarov found that bone formation was best if the cortex was divided using sharp osteotomes with careful preservation of the medulla and periosteum. This method causes less thermal damage than a saw but often leads to an irregular or comminuted osteotomy. Where close control of the direction of the corticotomy is required, the bone can be pre-drilled with a series of holes to encourage crack propagation in the right plane.

Latent period

There should then be a latent period of 5–7 days to allow the haematoma in the fracture gap to start to organise and establish neogenesis.

Distraction phase

This generally proceeds at about 1 mm per day. This corresponds to one complete turn of the adjustment nut on the frame as the pitch of the threaded rods is 1 mm. The distraction is performed in four divided increments per day as this is more comfortable for the patient and has been shown to promote better bone formation than a single daily distraction. Check x-rays are obtained after 1 week to check that corrections are occurring in the right direction and that any corticotomies are opening as expected (Fig. 1a). Follow up films are generally taken every 2–3 weeks thereafter to monitor progress of the distraction. The first signs of new bone formation in the distraction gap usually start to appear at week three or four. Fine wispy strands of calcified tissue reaching out from either side of the corticotomy are always a welcome sight as they confirm the viability of the bone ends and osteogenic activity (Fig. 1b). As distraction continues we like to see the new callus forming a solid, parallel-sided column of bone at each end. A gap usually remains in the middle of the regenerate where the most recent uncalcified osteoid is forming. The rate of distraction may need to be increased in children to avoid premature consolidation of this gap as they can form bone so rapidly. It may sometimes need to be reduced when the regenerate appears narrow or waisted or contains large defects. Some centres routinely ultrasound their regenerates to look for gaps or cysts but we have not found this particularly helpful. Towards the end of correction the length and alignment of the limb are checked using long-leg alignment films. It is important that these are taken perfectly square-on to the patient and with the legs straight and knees facing forward to enable accurate comparison to be made between the two limbs and to allow the mechanical axis to be estimated. A straight line drawn between the centre of the femoral head and the centre of the ankle joint should pass through or just medial to the centre of the knee joint. Fine corrections of the frame to get the alignment perfect are easily performed at this stage as the callus is still quite soft.

Consolidation phase

After cessation of lengthening, the newly formed woven bone is quite disorganised and soft (Fig. 1c). It usually takes about twice as long as the lengthening phase again for the bone to remodel and calcify enough to allow frame removal. Overall treatment time (in days) can therefore be estimated by multiplying the planned lengthening in millimetres by three. Bone remodels in response to the forces across it in accordance to Woolfe's law. Patients are therefore encouraged to engage in frequent weight-bearing exercise to stimulate calcification and remodelling of the regenerate. Initially, the regenerate has a homogenous ground-glass appearance on plain films. As time goes by, differentiation of a dense cortical line around a softer medullary cavity is seen. When this is seen on three sides of the regenerate (two views required) then we can make plans for frame removal. For the last few weeks in the frame, a little of the tension in the rods is backed off or one or two wires are removed to allow a little more force to be taken by the bone and 'dynamise' the regenerate. This is to try and accustom the bone to the extra load it will be taking when the frame is finally removed.

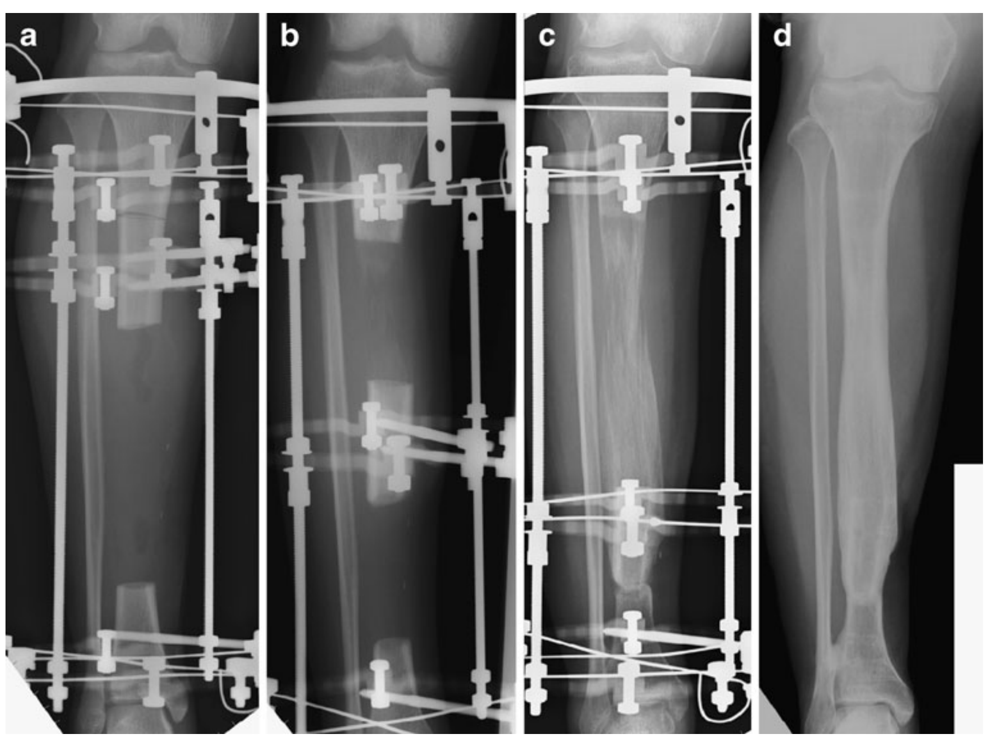

Fig. 1a–d An example of bone transport to replace a 15 cm tibial resection for tumour. **a** Frame construct with transport segment attached to middle ring; note corticotomy. **b** Part way through distraction; note wispy strands of calcified tissue in regenerate. **c** Distraction complete and transport segment 'docked' awaiting cortication on three sides before frame removal. **d** Six months after frame removal. Bone remodelling nicely. (Case courtesy of Mr. M. McNally, Nuffield Orthopaedic Centre)

Remodelling

As a precaution, once the frame is removed the limb is placed in a protective splint and weight-bearing is limited to 50% for the first couple of weeks. A check x-ray is then obtained to be sure there is no evidence of stress fracture or collapse of the regenerate before the splint is removed and weight bearing gradually increased. Over the following months and years, the newly formed bone continues to remodel (Fig. 1d) until it becomes almost indistinguishable from normal bone both radiographically and histologically. A trained eye can often pick out subtle clues that a lengthening has been performed for 10 years or more such as a slight streakiness to the bone or residual wire or half-pin holes. Whatever its appearance though, the beauty of the Ilizarov technique is that the bone that has been grown is living healthy tissue that will continue to remodel and resist the normal forces of life without the risks of loosening or fatigue that any implant may have.

Complications

The Ilizarov method is a long and complex process. The surgeons, nurses and physical therapists need to be on a constant lookout for problems such as pin site or deep infections, joint stiffness and contracture and neurological compromise. The radiology department can help us spot more subtle problems invisible to the naked eye.

Complications
Pin infection
Wire/pin breakage
Bone fracture
Delayed union
Refracture
Regenerate collapse
Joint contracture
Joint subluxation

The majority of pin-site infections resolve with 1 or 2 weeks of oral antibiotics but some go on to form a deep collection of pus. Ultrasound can be a helpful way of visualising and draining such a collection. If infection tracks down into the bone, a lytic zone forms around the area where the pin penetrates the cortex causing loosening of the pin, which is easily visible on plain radiographs. Once a pin is loose it is no longer adding to stability and is merely a foreign body that is best removed. Even after wire removal, a ring of dead sclerotic bone or 'ring sequestrum' can often be seen remaining which may need curetting or drilling out before the infection will settle. Chronic osteomyelitis is thankfully very rare after pin site problems, but it is not an uncommon reason for frame application in the first place so should be checked for on late post-frame treatment films. Since frames are often on for many months, metal fatigue can cause wire or pin breakage. These are often felt by the patient as a 'ping' but many are silent and should be looked for on all frame x-rays. Wires or half-pins through the bone can also act as a stress-riser which can cause an unintentional fracture to occur through the site of the pin; these are most common at the top or bottom wire of a frame at the junction of the supported and unsupported part of the bone.

The forces required to lengthen a bone are large, if great efforts are not made by the patient and physical therapist to keep all surrounding muscle groups stretched and mobile then joint contractures, subluxations and even dislocations can occur. Regular reviews of the hip and lateral knee x-rays should be made during femoral lengthening and any hint of subluxation must prompt an increase in physical therapy and stretching or a slowing or cessation of lengthening while the muscle catches up with the bone. Fracture or regenerate collapse after frame removal has been mentioned earlier, but because it is such a disappointment to get a problem which spoils the patient's euphoria after frame removal, it is always worth an extra glance at the films to check for the tell-tale hairline crack of a stress fracture or buckle (like a greenstick fracture) of an impending regenerate collapse. A little longer in a splint or partial weight bearing may prevent the need for a further frame or plating procedure. Most complications, if recognised and addressed early, do not go on to have long-term effects.

Summary

If you had a choice, you would probably not wish to undergo Ilizarov treatment; it is a long and stressful treatment and requires considerable effort. If you have a major deformity, massive bone loss or complex bone infection, however, the other options are even less appealing. Large allografts have high rates of infection, non-union and late fracture, and metal implants are at risk of loosening and fatigue particularly in younger patients. Sometimes the only other option is an amputation. The Ilizarov method offers the ability to correct deformity and grow new, normal bone which will continue to serve its purpose for the rest of your life.

Further reading

1. Rozbruch SR, Ilizarov S. Limb lengthening and reconstruction surgery. New York: Informa Healthcare 2007
2. Spielberg B et al. Ilizarov principles of deformity correction. Ann R Coll Surg Engl 2010;92:101–5