Flexible intramedullary nails for fractures in children

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Over the past few years there has been a marked increase in the use of intramedullary fixation in the management of fractures of long bones in children. To some extent this reflects a more interventionist attitude among paediatric orthopaedic surgeons but is also due to technical developments, notably that of the elastic stable intramedullary nail (ESIN).

The use of intramedullary devices to stabilise fractures is not new. In the mid-19th century, ivory pins were used for this purpose and were then gradually supplanted by various metal devices. These were generally rigid implants, although more flexible ones were introduced in the 1930s. The school of rigid intramedullary fixation was typified by the Küntscher nail, which achieved great stability in all planes by occupying the entire medullary cross-sectional area of the bone. However, its use in growing children was limited by the difficulties encountered in trying to avoid the physis.

The Rush nail was introduced at about the same time as the Küntscher nail. It was the forerunner of modern elastic intramedullary fixation in that the objective was to achieve three-point fixation on the inner aspect of the cortex. Unlike the stiff Küntscher nail, the Rush nail was slightly flexible and it was intended that it should be pre-bent to the appropriate configuration before insertion. Rotation stability was poor, however, and in most situations the flexibility was insufficient to allow insertion points in the metaphysis which were well away from the active physis in children.

Others, such as Hackethal and Marchetti, used bundles of thinner wires which filled the medullary cavity but with stabilisation achieved by splaying the ends of the wires within the bone well beyond the fracture. Ender developed this further with his nails, which were the first to feature adaptations to both ends of the nail in order to improve both control of insertion and quality of fixation. These nails could be safely inserted into the metaphysis which made them suitable for consideration in paediatric fractures.

In the early 1980s, surgeons in Nancy, France, developed an elastic stable intramedullary nail based on a theoretical concept by Firica. Previous experience had suggested that elasticity and stability were not easily combined in one construct. However, working from the concept of three-point fixation used with a single Rush nail, these surgeons were able to improve stability significantly by using two pre-tensioned nails inserted from opposite sides of the bone. Metazieau, Ligier and their colleagues were able to show that titanium nails which were accurately contoured and properly inserted could impart excellent axial and lateral stability to diaphyseal fractures in long bones. Rotational stability was also better than had previously been experienced, although this was to remain the weakest point of the technique. The use of titanium nails allowed greater elasticity than was available in the steel nails of the Ender system.

Most contemporary work on flexible intramedullary nailing in children's fractures is based on the Nancy experience, although there remain pockets of Ender and Marchetti enthusiasts. For the purposes of this review, flexible intramedullary nailing is taken to mean elastic stable intramedullary nailing using the concepts espoused by the Nancy group.

Principles of the technique

The ideal fracture for this technique is a transverse or short oblique diaphyseal fracture with minimal comminution in a long bone. However, such is the versatility of the method that the indications have widened considerably with time and personal experience.

The essential prerequisite is accurate pre-bending of an elastic titanium nail so that the apex of the bend will lie at the fracture site. A second nail of equal diameter is prepared to provide a diametrically opposed curve at the fracture site. The diameter of the nail should be...
two-fifths of the internal diameter of the medullary canal. Its length should be selected on the basis of pre-operative radiographs of known magnification, and confirmed on the limb before insertion.

In general, the insertion site will be in the metaphysis of the bone. It is tempting to make a small stab incision to make the insertion, but it should be remembered that these nails will also usually be removed, and it is difficult to explain to parents why the incision for removal is much longer than the original scar. Under fluoroscopic control, the cortex can be broached with an awl or drill according to individual preference. In younger children, in certain bones, and in cases of pathological fracture in osteopenic bone, it may be possible simply to use a curved haemostat. The selected nail is introduced and gently tapped along the medulla with the tip angled away from the cortex. The temptation to rotate the nail back and forth should be resisted. If possible, the fracture should be reduced by manipulation and the nail advanced across the fracture site. This is the time when careful rotation of the nail can be very useful in enabling the tip of the nail to gain access to the medulla on the far side of the fracture.

The elastic deformation of the curved nail in a straight medulla creates a bending moment which will tend to angulate the fracture. Insertion of the second nail in a similar fashion but from the opposite side of the bone will counteract this moment with an equal and opposite force. For this reason, both nails should be inserted up to the fracture site, the fracture reduced, and the nails tapped across the fracture site in an alternating manner for perhaps 1 to 2 cm into the far segment. Both nails can then be knocked home, leaving sufficient nail exposed at the site of insertion to enable subsequent removal.

If the contouring of the nails has been accurate, they will come to rest with their maximum separation at the level of the fracture, crossing in the medulla above and below this site. This so-called trifocal buttressing of each nail within the medullary cavity will impart the maximum stability to the fixation. This will nonetheless be far from rigid, and healing is characterised by the early appearance of the exuberant callus associated with micromovement.8

Fractures in the lower limb

Shaft of the femur (Figs 1 and 2). In the past, the majority of fractures of the femur in children were treated conservatively, and the only point of discussion concerned which form of traction was to be employed. Nowadays, pressure on hospital beds and the trend towards shorter stays in hos-
There is no indication for the use of ESIN in these fractures in children under the age of four to five years. These can be treated very satisfactorily in hip spicas, with or without preliminary traction. Thus, the lower age limit for ESIN in femoral fractures is probably about five years of age. The upper limit is more difficult to determine. Recent work has shown increasing angulation at the fracture site after ESIN stabilisation in older, heavier children. However, there is no ideal alternative. The risk of avascular necrosis of the head of the femur from the insertion of rigid intramedullary nails in teenagers is well described, and this form of fixation is best avoided while the proximal femoral physes remain active. ESIN can be used in the older child, but additional support in the form of a cast brace may be indicated if there is concern about stability. Thus, it may be reasonable to use ESIN up until the time of closure of the proximal growth plate, after which conventional rigid locked intramedullary nailing can be used safely.

The technique is as outlined above. Early intervention and the use of a fracture table make closed reduction much easier. In most cases, it is possible to allow the child to mobilise immediately with light partial weight-bearing, with or without a cast brace, depending on the weight and size of the child and the configuration of the fracture. The results in the age range of five to 14 years are excellent and compare well with those of either external fixation or treatment with a spica. The stay in hospital is generally for a few days only. The fracture heals typically within eight to ten weeks and the presence of the nails does not appear to impair bone healing. Non or delayed union is very uncommon and when it occurs may be related to the use of nails of inadequate diameter. Otherwise, complications seem to be limited to discomfort or skin tenting at the sites of insertion of the nail. These can be reduced by allowing the end of the nail to lie along the flare of the metaphysis; it should not be bent away from the bone. Growth disturbance appears to be minimal with a mean femoral overgrowth of only 1.2 mm. The originators of the technique recommended removal of the nail at about six months. However, at least one author has questioned the necessity of removal in the absence of symptoms in the child.

Shaft of the tibia (Figs 3 and 4). The tibia does not lend itself well to the potential benefits of ESIN stabilisation. The triangular cross-section makes it difficult to place nails in the symmetrically opposed configuration necessary for the technique to work properly. The marked proximal

Radiographs of a fracture of the mid-shaft of the tibia in a boy aged ten years a) AP and b) lateral views.

Radiographs of the same fracture from Figure 3 at union following intramedullary stabilisation with two flexible nails a) AP and b) lateral views.
metaphyseal flare and the presence of the tibiofibular articulation make antegrade nail insertion awkward. Additional protection with a cast is probably indicated, and under these circumstances, surgeons might consider the benefits of nailing to be marginal. Enthusiasts for the ESIN technique report good results, although casting of the limb appears to play a major role in management.11

Upper limb
Humerus. In children, most fractures of the humeral shaft can be managed conservatively and do not require treatment with an ESIN.

Fractures of the proximal humerus often involve the proximal physis and are generally Salter and Harris type-II injuries. The potential for remodelling is significant and some displacement is acceptable. In unstable fractures or in those which are significantly displaced, additional stability may be required. This may be afforded by K-wires inserted through the deltoid and across the fracture site or by the use of elastic nails. Two nails are inserted into the lateral column of the humerus at the elbow and passed distally to proximally. The physis and fracture site is crossed and the tips of the nails impacted into the head of the humerus. Both nails are inserted through a lateral point of entry, just proximal to the distal physis. Separate holes are made in the lateral column, one above the other. Once the fracture is stabilised, early mobilisation can be started as there is no muscle transfixation at the shoulder.

Fractures of the shaft of the humerus may require stabilisation with ESIN when conservative measures have failed or in the poly-traumatised child with multiple fractures of long bones.17 Again, two nails are used. The entry point for the nails is dependent on the level of the fracture. Fractures of the proximal and middle thirds can be stabilised with a pair of retrograde nails, as described above. Fractures of the distal third are stabilised with two antegrade nails. Both nails are inserted through a lateral entry point at about the level of the insertion at the deltoid. Separate holes are made in the lateral cortex, one above the other.

Paediatric orthopaedic surgeons are acutely aware of the challenges of the supracondylar fracture of the humerus, and many feel that the use of an ESIN in this situation adds further unnecessary challenges. Nevertheless, elastic nails can be used to stabilise supracondylar fractures.18 Two antegrade nails are used, with the aim of passing a nail down each column, across the fracture site and into the metaphysis. There is a steep learning curve to this technique, and for most surgeons the displaced supracondylar fracture will continue to be treated by reduction and K-wire stabilisation. Radius and ulna. It is in the forearm that treatment with the ESIN has probably had the greatest impact on management of fractures. Most orthopaedic units dealing with significant numbers of paediatric fractures now regard flexible intramedullary nails as the treatment of choice when internal stabilisation of these injuries is required.

A wide variety of intramedullary devices has been used. As well as titanium elastic nails,19-21 K-wires,22-24 Steinmann pins25 and reamed square nails26 have been used for the fixation of these fractures. Elastic nails and K-wires seem to be equally effective.27
Treatment with an ESIN is indicated for unstable, irreducible or open fractures, when non-operative management fails (Figs 5 and 6) and in specific circumstances such as Monteggia injuries (Fig. 7) and fractures of the head and neck of the radius (Fig. 8). These are situations where surgical management might otherwise involve fixation with a compression plate and screws. Although such internal fixation is a mechanically sound form of surgical stabilisation,\textsuperscript{28} it is associated with significant complications.\textsuperscript{29,30} Fixation with plates in children has given acceptable results but there are definite advantages in using the ESIN. The operating time is shorter, there is minimal soft-tissue dissection even if open reduction is required, cosmesis is excellent and the implant is easier and safer to remove.\textsuperscript{31}

**Technique.** A single nail is used for each forearm bone. Generally, a nail of 2.0 to 2.5 mm diameter is used, with the larger diameter employed if possible. The nail in the radius is inserted just proximal to the physis on the radial border. Care should be taken to avoid injury to the superficial radial nerve. An alternate point of entry is dorsally, adjacent to Lister’s tubercle. Use of this site can be associated with local discomfort on extension of the wrist post-operatively. The nail in the ulna is inserted just distal to the physis on the radial border. The point of entry is easily palpable and is proximal to the annular ligament and the head of the radius. Lascombes et al\textsuperscript{19} advocate that the two nails are pre-contoured although we have found that straight nails are equally effective.

The question arises as to whether both bones should be nailed. Clearly if only one bone is fractured, only one nail is required. If both bones are fractured and both of the fractures displaced then almost certainly two nails will be required. If one fracture is displaced and the other is not, then the displaced fracture should be reduced and the stability of the forearm reassessed. A second nail may not always be necessary.\textsuperscript{32}

Displaced, unstable fractures of the neck of the radius can be elegantly treated with an elastic nail inserted at the distal radius. The curved tip of the nail can be used as an aid to reduction of the fracture.\textsuperscript{33,34}

In most cases, Monteggia fractures can be managed conservatively with closed manipulation and application of a
plaster cast. On occasion, the fracture may be unstable and maintaining reduction of the radial head can be difficult with a plaster cast alone. An elastic nail can then be used. The nail is inserted at the tip of the olecranon and passed distally down the shaft of the ulna. The nail can be slightly contoured to assist in maintaining reduction of the head of the radius. This point of entry will result in the nail passing across the proximal physis of the ulna. We have not seen any cases of arrest of physeal growth.

Pathological fractures
Elastic nails have a useful role in the management of benign pathological fractures of long bones. The pathological fracture may be as a result of local bone weakness or more generalised pathology.

Local. Asymptomatic defects such as fibrous cortical defects or unicameral bone cysts can present as a fracture. In general, these fractures will unite and often the cyst itself will heal. The fracture can be treated by conservative methods but use of elastic nails has some advantages. As well as the stabilisation of the fracture, the nails will decompress the cyst, which will promote healing of the defect as the fracture unites.

Generalised. The most common cause of generalised bone weakness resulting in fractures is osteogenesis imperfecta. As well as presenting with an acute long bone fracture, osteogenesis imperfecta also results in progressive bowing of the long bones as a result of repeated micro-fractures. Elastic nails can be used to manage the acute fracture and also to stabilise corrective osteotomies.

Particular care should be exercised in the use of ESIN in osteogenesis imperfecta. Perforation through the abnormal cortex may easily occur, and the medullary canal may be very narrow. It is recommended that as long a nail as possible be used, and it may be necessary to perform exchange nailing as the child grows. Bending the end into a hook will prevent the nail from being pulled into the bone with subsequent growth. The nails should be left in place at least until the end of skeletal growth.

Discussion
The growing child has an astonishing ability to remodel its bones and in many cases will wipe out the evidence of a malunited fracture. It is probably fair to say that we are guilty of placing undue reliance on this phenomenon when poor conservative management results in deformity or shortening at the fracture site.

It is likely that the maximum acceptable residual deformity is probably less than that traditionally taught, particularly in the forearm in order to allow a full range of rotation of the forearm, and in the older child, where remodelling is less impressive. There is a role for a technique that ensures accurate and safe stabilisation of diaphyseal fractures of long bones in children.

In many respects, flexible intramedullary nailing fits the bill. It is safe, minimally invasive, appears to have few complications, does not interfere with growth, and is associated with short hospital stays and a rapid return to daily activity. However, these are also the features of a well-executed closed reduction and immobilisation in a well-moulded cast. Flynn et al, while reporting with enthusiasm on the result of flexible intramedullary nailing, pointed out that the majority of paediatric fractures of the lower limb can, and should, continue to be treated with closed reduction and immobilisation. While welcoming the undoubtedly benefits of flexible intramedullary nailing, we must ensure that the skills of manipulation of fractures and immobilisation in a cast are not lost.

Some questions remain: what is the upper age or weight limit for lower limb nailing? Is it necessary to remove nails, and if so, when? Is the theory of ESIN borne out in practice? Is it by no means certain that the ESIN devices offer any significant advantage in the forearm over simple K-wires. In general, however, flexible intramedullary nailing has deservedly become established as a front-line treatment for certain fractures of long bones in children. This technique should be part of the armamentarium of any orthopaedic surgeon who deals with paediatric trauma.

References