Elastic Stable Intramedullary Nail:

The viable technique for pediatric long bone fixation

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Treatment options for a pediatric diaphyseal fracture have been debated for a long time. Cast immobilization is used as a nonsurgical treatment to avoid risks from operations. However, casting has disadvantages such as shortening or angulation of the fracture site, difficulty in nursing care, and a delay in the return to school. Internal fixation has been indicated for some patients who cannot encounter those drawbacks. Elastic stable intramedullary nailing (ESIN) is one of the fixations of choice. Rational, surgical techniques and possible complications of ESIN are reviewed in this article. Benefits from this treatment system are that it is a minimally invasive procedure, the promotion of callus formation, easier nursing care, and early ambulation. There are some complications from this technique which were proposed as minor and major complications. Soft tissue irritation around the entry point of the nail is the most common minor complication whereas unacceptable angulation has the highest incidence among major complications.

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Introduction

Non-surgical treatment for pediatric long bone diaphyseal fractures was accepted by orthopaedists for a long time. The reported nonunion rate was more than 90% and full functional recovery[1,2]. Early casting immobilization or traction followed by casting were the standard for children who suffered from fracture of the shaft of a long bone[3]. Presently, surgical treatments are generally indicated for an unstable fracture, an open fracture, a fracture associated with a neurovascular injury, or a multiple injury patient. Ideally, the internal fixation should be less invasive, provide immediate stability, and not interfere with the growth plate or blood supply[4,5]. Successful treatment with an external fixator, submuscular plating, and intramedullary nail were reported[4].

The advantages of having surgical treatment are as follows: children can regain function earlier than having a non-operative treatment, easier for nursing care, less psychological problems, and a shorter hospitalization period[5,6]. Disadvantages of the nonsurgical treatment were also reported, such as unacceptable shortening of the extremity, prolong duration of immobilization, delayed return to school, difficulty to transfer, and psychosocial disturbance; thus a surgical intervention may be needed to obviate those mentioned problems[2,7]. For some conditions, such as a fracture of the femoral shaft in adolescent or obese patients, an operative treatment was preferred[1,8,9]. Different options of management are available depending on various factors such as age, type of fracture, level of fracture, associated injuries, social issues, economical constraints, and psychological issues[10].

Evolution for intramedullary nail fixation

At least 5 types of intramedullary nail have been invented and used as a fixation material for a long bone diaphyseal fracture in children. The Küntscher nail, Hackethal’s bundle nail, and Rush pin were among the first group developed. There were some complications reported associated with these instruments, such as growth plate injury or avascular necrosis of the femoral head[11]. The Sevilla-Eiffel Tower system, using multiple Kirschner wires (K-wires) inserted percutaneously into the femoral canal by a retrograde technique was proposed. Limiting of the wire length and thickness of custom-made K-wires caused poor acceptance for this technique[11].

The Ender nail was introduced in 1970. The nail was designed initially for an adult femoral fracture. Then it was adapted to pediatric groups. The concept of the Ender nail is similar to elastic stable intramedullary nailing (ESIN). Some studies reported that the Ender nail had insufficient elasticity to control a fracture and may interfere with the normal bony curvature[12].

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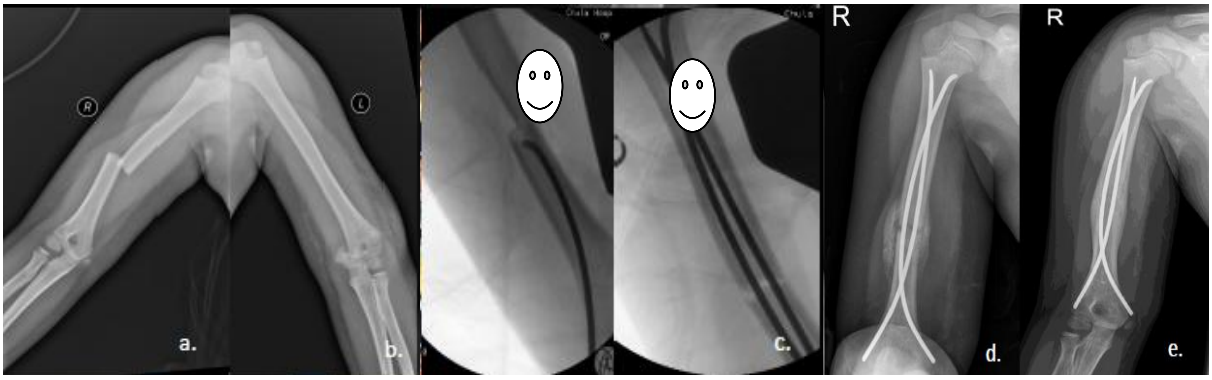
ESIN, Nancy nail, and titanium elastic nail

This intramedullary nail was developed in 1988 by Nancy, France, and was called by different names, e.g. Nancy nail or titanium elastic nail (TEN), and is available in stainless steel or titanium. It was described as embrochage centro mé-dullaire elastique stable (ECMES) system. It is one of the accepted minimally invasive treatment options for pediatric long bone fractures[13,14] which appropriates for children between 5-16 years of age. This system is slightly different from the Ender nail. The Ender nail was a “stack nailing” inside the medullary canal and is stiffer. ESIN is a “canal filling” and has more elasticity than the Ender nail. ESIN insertion by a minimally invasive technique was recommended. After close reduction is performed, nails are introduced into metaphyseal entry points; they create three point pressures to stabilize the long bone fracture. Following these techniques, patients would obtain benefits from minimal blood loss as well as the retainment of periosteum and fracture hematoma which promote the bone healing process[11] (Fig. 1). The system stimulates a rapid development of bridging callus and allows early weight bearing[15]. The rotational instability and an unequal limb length are the most major concerns associated with the ESIN. High cost for the material may affect patients in low socioeconomic areas[16-18]. Flexible intramedullary nails are manufactured in varying diameters and lengths. Surgeons must choose the proper nails for each patient[13].



(a) (b) (c) (d) (e)

(f)

Fig. 1 A 7 year old boy came following a car accident. He had multiple fractures and right radial nerve palsy after the car accident.
(a) Closed fracture shaft of the right humerus.
(b) Closed supracondylar fracture of the left humerus.
(c) ESIN was used for the right humeral fracture.
(d) 1 month after the operation, external callus was formed.
(e) 2 months after the operation, the humerus was completely healed.
(f) The patient’s radial nerve function at 5 months follow up.

Biomechanics of the ESIN

The material properties of the ESIN are superior in various aspects compared with that of stainless steel nails. The modulus of elasticity of 316L stainless steel is 80% stiffer than titanium (187 Gpa for the former and 105 Gpa for the latter). The more favourable elasticity of titanium promotes callus formation by limiting stress shielding and allows micro-motion at the fracture site(4,13,18). From several studies, they recommended using two symmetrical nails for occupying 80% "canal fill" of the fractured bone. Each nail should have a diameter of approximately 40% of the narrowest part of the intramedullary canal. Stability was tested using a synthetic femoral bone model and showed that at 78% of canal fill both axial rotation and compression stability were at the maximum increase. In contrast, the larger canal fill would improve only a rotational stability(19,20). Hypertrophic nonunion was reported as the complication of using an undersized nail(21).

Fracture configurations affect the stability of the ESIN fixation system. An experiment was performed by creating 5 different fracture patterns on a synthetic femoral bone. Rotational stability was tested after the synthetic bones were reduced and ESIN was applied as a standard protocol. The oblique type fracture exhibited the strongest of torsion stiffness in an internal rotation, while the spiral fracture pattern was the largest for external rotation stiffness. Torsion stiffness between the transverse fracture and the comminuted fracture did not have a statistically significant difference. They concluded that the rotational stability did not differ in a variety of fracture patterns in these synthetic models(22). Although increasing the nail diameter can improve the rotational stability, some authors believed that muscle around the fractured bone acts as "guy ropes" and the muscle action participates in spontaneous correction of angular deformity(4).

The torsion and axial compression testing in a femoral bone model did not show a difference between stainless steel and titanium nails. The author concluded that the stainless steel nail is significantly stiffer than titanium, but this is not related to the rotational stability(23). Because of less stiffness, it is possible for the titanium nail to deform within the medullary canal. This increases the contact area leading to resistance of a compressive and torsional load. The finite element analysis study revealed a greater deformation and increased contact area of titanium nails than stainless steel nails. Moreover, the experiment showed a higher degree of slipping from the canal of stainless steel nails. The amount of fracture gap closure for the femur which was fixed with the titanium nail was maintained in the range of micromotion of normal bone healing(13).

One of the important risk factors for ESIN of the femoral shaft fracture is the patient's body weight. The average load required for a sagittal plane failure was 628 N and 596 N for a coronal plane. This corresponds with the bending moment of the femur during the gait in a patient who has a body weight of around 40-45 kg. Being overweight was proven to be a risk of fixation failure and loss of reduction or risk of angulation of at least 15 degrees, especially for midshaft femoral fractures(24).

Techniques for long bone diaphyseal fracture fixation

Pre-bending of the nail is the important step for ESIN (Fig. 2). A biomechanical study which compared the stability of bending nails to various degrees showed the result of the nail, which was pre-bent for 45 degrees, provided the greatest stability in both sagittal and coronal plane. When nails were pre-bent to 60 degrees the sagittal stability was decreased(25). In some institutes, the surgeons recommended that a nail should be pre-bent over the length of the bone three times the diameter of the medullary canal.

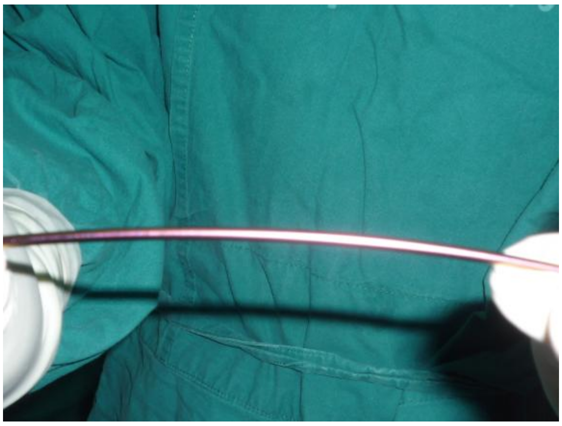


Fig. 2 A nail was pre-bent by a manual technique.

Two requirements for this technique are a fluoroscope and a radiolucent operative table or fracture table. The nails are gently contoured to a 45 degree angulation at about 2 cm from one end and are also contoured over their entire length. A hole is made at the distal femur metaphysis just proximal to the distal femoral growth plate by using an awl or drill bit. The fracture was reduced and checked for position by fluoroscope. Two nails are used, one for medial and another for lateral, then the contoured nails were inserted into the hole and passed into the medullary canal.

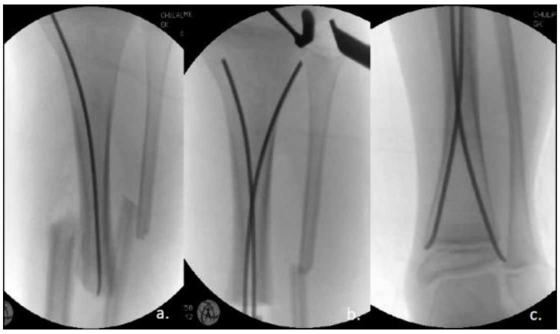
For femoral shaft fractures, a retrograde technique is used to prevent proximal growth plate or vascular injury. Both nails must be introduced at the same level and contoured to identical curvatures; these are the important techniques to prevent fracture malrotation. The nail ends are cut at about 1-1.5 cm distal to the bone cortex[15]. Antegrade nailing was properly used for distal femoral fractures. By the antegrade technique, the entry point is changed to the subtrochanteric area just below the greater trochanter. In other long bone fractures, the same principle is applied for intramedullary nailing. The entry point of nails can be changed depending on the anatomy and how to avoid injuring the growth plate[26].

Once they are in the medullary canal, the staggering pattern of both nails is another factor that may affect their fixation properties. Several studies suggested "C" shape contouring of the nails before they are applied. A divergent "C" configuration provided significantly greater rotation stability and compression stiffness[15,19,25]. For the divergent "C" construct, each nail has three points of fixation at the entry point, apex of the curve, which is the same level as the fracture site, and at the nail tip. This construct produces the most suitable "elastic stability" for the fractured bone. A two straight-nails construct showed less stiffness than the divergent "C" but was not statistically significant[25].

The tip of the nails is left outside the metaphyseal cortex. This may irritate the soft tissue around them and decrease the range of motion due to pain[4]. Various techniques were suggested to decrease this complication from nail irritation. An end cap for ESIN was proposed. A cylindrical hollow threaded end cap was easily applied by screwing into the cortical bone until it has a firm grip. However, using end caps may interfere with the bone healing process because it decreases the stability of the construct and limits micromotion of the fracture site. Some surgeons reported delaying of callus formation[27].

Complications

Complications related to the treatment of pediatric long bone diaphyseal fractures with ESIN were found in many reports, especially for femoral fracture treatment[4,12,14,28,29]. Minor complications include pain at the insertion area, acceptable degree of angulation and limb length discrepancy, inflammatory reaction due to nail tip irritation, and skin infection. The major complications which need a second operation are an unacceptable angulation, loss of reduction, severe limb length discrepancy, and deep infection[29]. A retrospective review of 234 femoral fractures revealed a 30.4% rate of minor complications with the most common being pain at the insertion site. This usually happened when the nail end was left too long or a nail slippage and back out occurred and thus led to an irritation of the soft tissue around it (Fig. 3). Superficial skin infection and a deep wound infection may occur. Limiting motion of the adjacent joint from pain and delaying of weight bearing relates to this problem[12].



(a) (b) (c)

Fig. 3 A 9-year-old boy, osteogenesis Imperfecta, came with malunion of the left tibia. Corrective osteotomy was performed and ESINs were used for fixation.
(a) The first nail was passed from the proximal part of the tibia.
(b) Both nails were passed across the osteotomy site.
(c) It was noticed that the first nail was too long. This leads to soft tissue irritation and the need to remove later.

As described in the previous part, end capping is a technique which decreases this complication[27]. However, there are various procedures described for preventing this minor complication. Cutting the end nail and keeping it close to the cortex without bending was suggested[30]. The length of the nail end left outside the metaphyseal cortex should be less than 1.0-1.5 cm to reduce the incidence. It should not advance into the medullary canal. Some surgeons suggested not leaving the end of nail distal to the growth plate[12,28]. For the back out nail, the end of the nail should be trimmed and advanced to the proper position. Flexible nails may need to be removed after the fractured bone has completed union[4,12,15,21,31].

A major complications rate of about 18%, of which the most common was an unacceptable angulation was reported[29]. The average degree of angulation after using ESIN for femoral shaft fractures is about 5-20 degrees in both the coronal and sagittal planes[8,32]. Closed reduction for the fracture site is one of the risks for malrotation because anatomical reduction was difficult to obtain[33]. The complications are commonly associated with children of more than 11 years of age, over 50 kg of body weight, and unstable fracture configuration[8]. Factors affecting the stability of the ESIN construct included mismatching of the nails size and using of too small diameter nails. The wrong technique for nail bending leads to a malrotation of the fracture bone. A previous study reported an association with an odd ratio of 19.4 between malunion and/or a loss of reduction which required a second operation by using mismatched diameter nails[12].

Fracture configuration is another factor related to a malrotation after reduction. Almost 20% of complications occurred in "length-unstable" fractures such as long oblique or comminuted fractures[28]. Pulling of the thigh muscles can induce an external rotational malalignment of femoral fractures which were treated by ESIN[33]. Some authors suggested some form of postoperative immobilizations such as casting or bracing for the patient who had these risks of fracture malalignment until callus formed[4,15]. A small number of patients were reported to experience limb length discrepancy and need a second operation. The average discrepancy of limb length was between 1-1.5 cm. Causes of limb length unequal after ESIN are similar to those of malrotation which are fracture configuration and nail slippage[29,33].

In conclusion, the ESIN is the most recent advance in pediatric diaphyseal fracture care. Although not a totally new idea, the use of titanium and a better biomechanical study bring us the understanding of the proper use of this minimally invasive fracture fixation option. Meticulous care should be exercised in terms of patient selection and the most suitable fracture configuration before the ESIN should be chosen. Most of the complications can be avoided if the recommendation is strictly adhered and an excellent healing rate can be expected. Our children and society will have a benefit from this advance surgical technique.

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แกนโลหะยึดในโพรงกระดูกชนิดยืดหยุ่นและมั่นคงสำหรับกระดูกหักในเด็ก

พัชราภา โอสธีรกุล, พบ, ณพชาติ ลิมปพยอม, พบ

การรักษาภาวะกระดูกหักบริเวณก้านกระดูกยาวในเด็ก วิธีรักษาตามมาตรฐานคือ การใส่เฝือก แต่พบว่าในบางกรณี การรักษาเช่นนี้อาจให้ผลไม่เป็นที่น่าพอใจ เช่น การเกิดภาวะกระดูกติดในลักษณะที่ผิดรูป หรือมีความแตกต่างของความยาว เมื่อเทียบกับแขนหรือขา ข้างปกติ นอกจากนี้ การดูแลภายหลังจากการใส่เฝือกค่อนข้างยุ่งยาก ส่วนใหญ่สร้างความลำบากต่อการใช้ชีวิตประจำวัน เช่น ต้องขาดเรียนเป็นเวลานาน การรักษาโดยการผ่าตัดใส่แกนโลหะยึดในโพรงกระดูก จึงมีที่ใช้ในผู้ป่วยบางราย การศึกษานี้ได้ทบทวนวรรณกรรมที่เกี่ยวข้องกับการรักษากระดูกหักในเด็กโดยใช้ elastic stable intramedullary nail ซึ่งนิยมใช้กันแพร่หลายมากขึ้นในปัจจุบัน การรักษาด้วยวิธีนี้ข้อดีคือ ช่วยหลีกเลี่ยงภาวะไม่พึงประสงค์เมื่อรักษาโดยการใส่เฝือก อย่างไรก็ตาม มีรายงานภาวะแทรกซ้อนที่เกิดตามหลังการผ่าตัดใส่แกนโลหะยึดในโพรงกระดูก ด้วยวิธีดังกล่าว เช่น การระคายเคืองต่อเนื้อเยื่ออ่อนรอบจุดเข้าของแกนโลหะยึดในโพรงกระดูก หรือกระดูกติดผิดรูป ถึงแม้ว่าผู้ป่วยได้รับการรักษาโดยการใส่แกนโลหะยึดในโพรงกระดูกไปแล้ว ซึ่งในกรณีหลังนี้ พบได้ไม่บ่อย แต่มักเป็นเหตุให้ผู้ป่วยต้องเข้ารับการผ่าตัดแก้ไขซ้ำอีกครั้ง