Principles of Fixation with Interlocking Nailing

Abstract
The history of the new nailing method dates back to Gerhard Küntscher, who introduced this concept in Germany in 1940. He believed in two general principles: Stable fixation and fixation of fractures without opening the fracture site. In the beginning, primary nails with various weaknesses were only used in fractures of femur. Over time, effective changes were made in the design and insertion of bone nails. This article aimed to review the evolution of the design of nails and simple but significantly important principles of inserting nails in long bones. In any case, lack of adherence to these simple principles by surgeons leads to lack of desirable fixation.

Keywords: Nailing, Locking, Long Bones

Received: 15 months before printing; Accepted: 1 month before printing

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Nailing History
The turning point for the new nailing method dates back to Gerhard Küntscher \(^{(1)}\). In 1940 in Germany, he introduced new nailing methods and followed the principles of obtaining stable fixation and fixation of fractures without opening the fracture site. Nonetheless, the history of using nails dates back to the 16\(^{th}\) century AD, when the indigenous peoples in Mexico used wood as intramedullary fixator for fixation of nonunion of long bones. In the 18\(^{th}\) century, ivory of animals and even other long bones of humans were applied as intramedullary fixators.

In 1947, the new approach of Küntscher reached the United States. Today, this method is recognized as an efficient technique for fixation of long bone fractures in most parts of the world \(^{(1)}\).

What is the reason for the superiority of nailing over plating?
As observed in Figure 2, the distance of the nail inside the bone is shorter than the center of pressure applied to the bone. Therefore, greater power is required to bend the nail. Meanwhile, since plates are placed in a farther distance from the center of force, they can be bent by less power \(^{(2)}\). In addition, the nail inside the bone along with locking has proper bending, compressive, and rotational rigidity (Figure 3).

Biomechanics of Intramedullary Nails
Resistance of intramedullary nails to various forces depends on the effective factors presented below \(^{(3)}\):
- Nail design
- Rimming or lack of rimming before inserting the nail
- Numbers and direction of placement of locking screws
- Distance of placing locking screws from the fracture site
- Patient bone quality
Nail Design
Properties of Ingredients of Nails
The ingredient of most nails is stainless steel. In the new generation of nails, titanium is also used as an ingredient (4).

Gradual evolution of the cross-section shape of the nails (3)
In the beginning, Küntscher used nails as portrayed in Figure 7. These nails could only be inserted in one direction. Application of these nails was prohibited in 1947 and they were replaced by nails in the shape of cloverleaf and were able to tolerate the pressure applied in two directions perpendicular to each other (Figure 4).

While the primary nails were designed solid, they were turned into hollow nails through more evolution so that they would adapt to bone canals more easily (Figure 5).

Until 1980, various types of nails (in terms of cross-sectional shape) were introduced. As observed in Figure 6, the new generation of nails has no grooves, which makes them more resistant to rotational force (5).

Nail Diameter
Nail diameter had a significant effect on their bending rigidity. Nail bending rigidity has a direct relationship with its third diameter power (D^3). In addition, rotating rigidity of nail is equal to the fourth diameter power (D^4). With equal cross-section, a nail with a higher diameter will have more power and resistance to the pressures applied (5).

Nail Curvature
The bone canal of the long bones is curved. Therefore, new nails were designed in a way that they could adapt to the curvature of long bones to some extent. Nails designed for femur have less curvature than the natural curvature of this bone. Nails designed for Tibia bone have an angle known as Herzog to the back between the first one-third and the last two-thirds (Figure 7). The matching of curvature of the nails with the curvature of long bones leads to the prevention of damage to the cortex of bones during their insertion. In addition, there is no need for excess rimming of the bone (6).

Rimming or Lack of Rimming before Nail Insertion
The canal of long bones is more like an hourglass, where the mid part is narrower than the two ending parts. Therefore, it is attempted to create a uniform cylinder in the bone canal by rimming and expansion of the canal in order to create a suitable place for the nail.
The canal diameter determines the required diameter of the nail. Rimming leads to the flattening of the internal surfaces of the bone canal, followed by increased contact between the nail and the bone cortex. In this regard, there is a 38% increase in the contact between the nail and the internal cortex of the bone per each millimeter of rimming. Rimming enables us to use nails with higher diameters. Since this type of nail has more bending and rotational rigidity, it increases the stability of fixation.

As observed in Figure 8, two-thirds of the bone marrow cortex perfusion is endosteal. Therefore, it could be concluded that rimming damages the internal perfusion of the cortex. As such, it is better to use sharper rimmers with deeper flutes in order to decrease this damage and perform the reaming in a calm and continuous manner (7).

Despite the damage to bone cortex perfusion after rimming, several studies have shown that this damage can be quickly reversed. Therefore, the possibility of infection or union time of the bone has no difference with nailing without rimming. In addition, rimming increases the possibility of fat embolization of bone marrow to the lung despite the fact that this phenomenon is limited and transient. Statistically, various studies have concluded that there is no difference between the two groups of nailing with and without rimming in terms of pulmonary complications.

In case of a decision for nailing along with rimming, the important note is preoperative planning, where it is better to focus on the
type of fracture using proper graphies in order to determine the length and diameter of the nail before the operation.

- The graphies can be used to determine the fracture site, type, and degree of comminution (8).
- To determine the length of the femoral nail, the distance between the greater trochanter and the lateral epicondyle of the femur in the opposite site can be used, whereas the distance between tibial tuberosity and medial malleolus on the other side was applied to determine the length of tibia nail.
- To determine the diameter of femoral nail, the narrowest part of the femur in isthmus will be measured in the lateral graphy of the femur.

- Rimming must continue about 1-1.5 mm more than the diameter determined (9).
- The nail insertion site can be determined properly at the beginning of femur and tibia bones (Figure 9).
- After inserting the nail, the guide wire with a rounded end will first insert into the bone canal, will pass the fracture site, and will place in the subchondral part of the end part of fracture. Following that, rimming initiates with sizes 8.5-9 mm.
- The first time the rimmer will pass through the fracture site, the suitable process of rimming will be checked by a fluoroscope.
- Rimming carries out with 0.5-1 mm distances.
- Nailing in open fractures:
  In open fractures, if the initial debridement is performed completely, then nail along with rim can be used as a definitive fracture fixation.
  In cases of severe soft tissue injury, external fixation can be applied at first, which can be turned into internal fixation by nail after 5-10 days (10).

Nailing in multiple trauma patients:
  In these patients, quick fixation of the femur reduces the incidence of fat embolism and pulmonary complications.
  Nail insertion along with rimming does not increase pulmonary complications.
  In high-risk patients, it is suggested to take perform the fixation in a step-by-step manner (11).

Locking Screws:
Nailing with locking screws was first introduced by Mondy & Barbara, who applied crossed nails with several holes.
After the emergence of locking screws, the nail lengths were described in two ways: the overall length, or anatomical length of the nail, which is A length in Figure 10.
Functional length of the nail, which is, in fact, the length of the nail that is placed between the fixation of the tip and end of the nail to the bone by screws.
Today, the interlocking nail is recommended in most nail applications. In general, the use of locking screws increases the resistance of nail to rotation and compression. However, the number of locking screws depends on the fracture site and the degree of comminution. The location of the end screws has a profound effect in the biomechanics of the fracture. As observed in Figure 11, the closer the screw is to the fracture site, it is exposed to more pressure. Therefore, the distance between the screws at the end of nail to the fracture site should be at least two cm to increase fracture stability (12).

Screws with more diameters are applied to have more stable interlocking screws. For instance, screws with a diameter of 5-6 mm are used for femoral and tibial bone nails.
As shown in Figure 12, the interlocking nails are under pressure from four points.

![Figure 12.](image1)

the number of screws used for nail locking depends on the fracture site and its stability. A fluoroscope can be used to place the screws of the distal interlocking nails (Figure 13).

![Figure 13.](image2)

The locking screws can be positioned in static and dynamic modes. Generally, static locking screws are used in fractures with high degrees of comminution, spiral fractures, and fractures along with a bone loss in order to minimize rotation and displacement at the fracture site. In fractures of the bone with at least fifty percents of the contact surface or in the absence of bone union, for fixation, a nail with a dynamic lacing screw can be used. In this way, only screws of shorter fragment can be placed. Another way is placing the proximal screws in the dynamic hole (Figure 14).

![Figure 14.](image3)

New Changes in Nails in the 21st Century
Nail designs have been changed in a way that they can be used for fixation of fractures at the proximal or distal of long bones in addition to shaft of long bones. (14)

Fracture at the beginning of the femur
Cephalomedullary nail is used for this type of fractures. As observed in Figure 15, the nail is placed at a lower distance from the center of applied pressure. Therefore, less pressure is put on the nail and the chance of fixation loss is reduced. (15) According to figure 16, the first locking screw is placed in the femoral head and neck section. Some of these nails include Gama nail and reconstruction nail.

- Fracture at the end of the femur (16):
  To fix these fractures, the nails applied can be entered into the bone canal from the end of the femur and be fixed both in the end and the beginning parts with locking screws (Figure 17).

- Fracture of the proximal third of tibia:
  These fractures tend to be angulated in the form of valgus and the proximal part displaces forward. Therefore, Poller screws can be applied to prevent the angulation and displacement of the fracture during nailing since these screws can guide the nail in the proper direction.
As observed in Figure 18, Poller screws can be exploited in the lateral and posterior part of the nail in the proximal segment to guide it\(^{(17)}\). Among the recent advances of nails are:

- Use of absorbable polymers for the production of nails
- Application of nickel-titanium alloys that adapt themselves to the form and curvature of bones with body heat.
- Use of nails that are covered by bone morphogenetic protein (BMP)\(^{(18)}\).

![Figure 15.](image1)

![Figure 16.](image2)

![Figure 17.](image3)

![Figure 18.](image4)
References