INTRODUCTION

Intramedullary (IM) nailing is considered the gold standard treatment of closed and many open femoral, tibial and humeral shaft fractures due to its biomechanical and biological advantages [1].

However, major complications following this procedure includes infection, compartment syndrome, venous thrombosis, fat embolism syndrome, neurovascular damage and nonunion. All these complications could have a significant impact on the ultimate functional outcome of the patients [2].

The incidence of infection after internal fixation of closed fractures is generally lower (1−2%), whereas the incidence may exceed 30% after fixation of open fractures. Due to the absence of well-designed studies with a sufficient follow-up period, diagnosis and treatment of implant-associated infections is mainly based on tradition, personal experience, and liability aspects, and therefore differs substantially between institutions and countries [3].

Infections after internal fixation are classified into those with early (less than 2 weeks), delayed (2−10 weeks), and late onset (more than 10 weeks) [4].

Infections with delayed and late manifestations are usually grouped together, since their clinical presentation, treatment, and prognosis are similar [5].

The critical factors influencing the risk of developing infection were the complexity of fractures and not the techniques used [6].

Chronic osteomyelitis as a complication of IM nail fixation of long bone fractures is commonly polymicrobial in 70 % of patients. The most common infecting organism is staphylococcus aureus [7].

The meticulous clinical evaluation, detailed diagnostic work-up and a specific treatment strategy are critical factors in diagnosing the presence of infection after surgical procedure of long bone fractures [8].

Depending on the extent of infection, timing of diagnosis and progress of fracture healing, different treatment options have been developed. There is no hard and fast rule for the treatment of chronic osteomyelitis related to implant. Still now it is a big challenge for orthopedic surgeons to handle such cases. Some options are very costly and time consuming [9].

The goals of treating infection associated with internal fixation devices are consolidation of the fracture and prevention of chronic osteomyelitis. Thus, in contrast to prosthetic joint associated infection, complete eradication of infection is not the primary goal, since the device can be removed after consolidation. The nature of the surgical intervention in patients with infected fracture-fixation devices depends on the type of device, the presence or absence of bone union, and the patient’s underlying condition [10].

AIM OF THE WORK

The aim of this review is to collect and analyze the existing evidence related to the incidence and management of infection following IM nailing of femoral fractures published in literatures in English from 1994 to 2015, and to recommend treatment algorithms that could be valuable in everyday clinical practice.

BIOMECHANICAL AND BIOLOGICAL ADVANTAGES OF INTRAMEDULLARY NAIL FEMUR

The intramedullary (IM) nail or rod is commonly used for long-bone fracture fixation and has become the standard treatment of most long-bone diaphyseal and selected metaphyseal fractures. To best understand use of the IM nail, a general knowledge of nail biomechanics and biology is helpful. These implants are introduced into the bone remote to the fracture site and share compressive, bending, and torsional loads with the surrounding osseous structures. IM nails function as internal splints that allow for secondary fracture healing (11).

I- Biomechanics of IM Nails

When placed in a fractured long bone, IM nails act as internal splints with load-sharing characteristics (12).

The amount of load borne by the nail depends on the stability of the fracture/implant construct. This stability is determined by several factors, including (11,12,13).

- Nail size
- Number of locking screws or bolts
- Distance of the locking screw or bolt from the fracture site.

IM nails are assumed to bear most of the load initially, then gradually transfer it to the bone as the fracture heals [13].

In current practice, with reaming of the canal and the use of locking screws, physiologic loads are transmitted to the proximal and distal ends of the nail through the screws [11,12,13].

When interlocking screws are absent, the implant acts to guide the motion of the bone along the longitudinal axis of the nail. The friction of the nail within the medullary cavity determines this resistance to motion.

This friction between nail and bone is affected by:

- The amount of bending of the nail (curvature)
- Its cross-sectional shape (particularly the geometry of the surface of the implant)
- IM nail diameter
- As well as the corresponding properties of the canal (eg, size, shape, bone quality) [13].

Three types of load act on an IM nail (Figure 1):

- Torsion
- Compression
- Tension

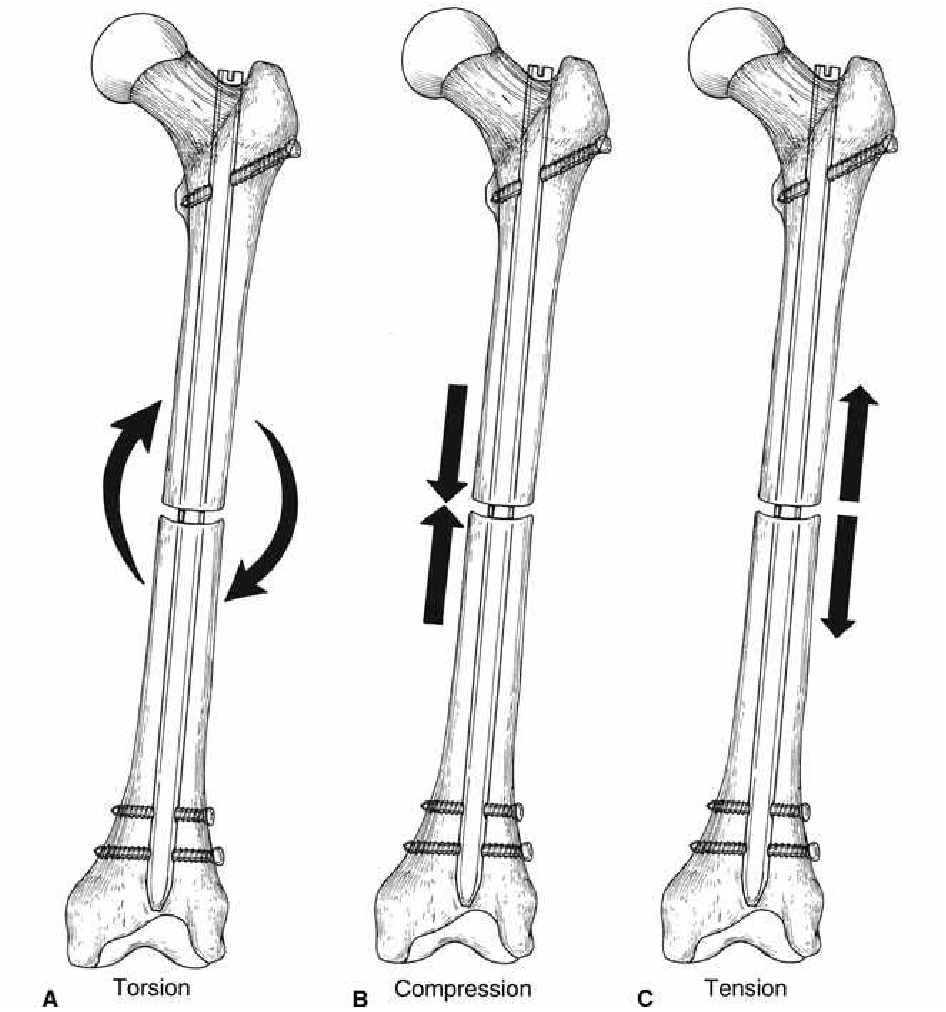

Fig. (1): The physiologic loading that acts on a nail involves torsion **(A)**, compression of the medial aspect of the nail **(B)**, and tension on the lateral aspect of the nail **(C)** (13).

Physiologic loading is a combination of all three. Similar to the intact femur, in which loading of the offset femoral head causes a bending moment in the femoral shaft, bending of the nail under loading creates compressive forces on the concave side of the nail and tension forces on the convex side. When cortical contact across the fracture site is achieved postoperatively, most of the compressive loads are borne by the bony cortex; however, in the absence of cortical contact, compressive loads are transferred to the interlocking screws, which results in four-point bending of the screws (Figure 2) [14].

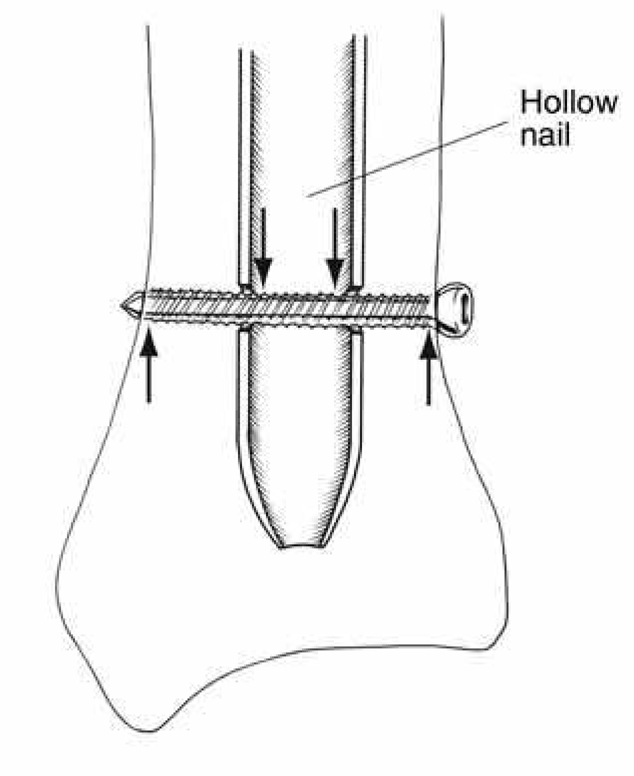

Fig. (2): Four-point loads (arrows) acting on a distal interlocking screw. Under axial load, and in the absence of cortical contact, bending of the screw and screw failure may occur [14].

As with all metallic implants, there is a relative race between bone healing and implant failure. Occasionally, an implant will break when fracture healing is delayed or when nonunion occurs. Unlocked nails typically fail at the fracture site. Locked nails fail by screw breakage or fracturing of the nail at locking hole sites, most commonly at the proximal hole of the distal interlocks [14].

1- Nail Characteristics

Several factors contribute to the overall biomechanical profile and resulting structural stiffness of an IM nail. Chief among them are [11]:

- Material properties
- Cross-sectional shape
- Diameter of IM nail
- Degree of anterior bow of the femoral nail.

Material properties

The two most frequently used materials in the construction of IM nails are titanium alloy and 316L stainless steel. Titanium alloy has a modulus of elasticity that is about half that of 316L stainless steel, but it more closely approximates the modulus of cortical bone. The stiffness or rigidity of a nail depends both on the material and its design. In biomechanical testing of IM nails with similar designs, ***Aitchison et al.*** [15] showed that although the stainless steel nails had 25% more torsional rigidity than did the titanium alloy version, their ultimate strengths were similar.

Im and Shin [16] found a high breakage rate (8%) of titanium locking screws in femoral shaft fractures and recommended the use of two distal screws. However, this finding could be attributable to the smaller diameter of the titanium nails and higher loading of the screws. Although there are measurable differences between titanium alloy and 316L stainless steel in the laboratory, the clinical results with either material appear to be equivalent.

Cross-sectional shape

The cross-sectional shape of the nail affects its torsional rigidity and the amount of contact within the medullary canal. Because most nails are similar in design, the cross sectional shape has little effect on the bending stiffness of the nail; most nails are within 15% of each other in this regard [17].

Diameter

Nail diameter affects nail bending rigidity. For a solid circular nail, the bending rigidity is proportional to the nail diameter to the third power, and the torsional rigidity is proportional to the fourth power. Femoral fractures fixed with interlocked nails can withstand greater than four times body weight before failure, whereas biomechanical studies have shown that femoral fractures fixed with interlocked nails have 25% less bending rigidity than do intact femurs. Diameter also affects nail fit; a well-fitting nail can help reduce movement between the nail and bone and maintain fracture reduction [17].

Degree of anterior bow of the femoral nail

The anterior bow of femoral nails affects the frictional fit within the canal of the femur and is an important factor in nail insertion. Anthropologic studies have shown that the average radius of curvature of the human femur is 120 (±36) cm [(18)].

Current femoral nail designs have considerably less curve, with radii ranging from 186 to 300 cm. Nails with a smaller radius of curvature mismatch are easier to insert but have less frictional fixation. With a larger mismatch, frictional fixation is increased; however, insertion is more difficult. Insertion of nails with a large mismatch of curvature with the bone can cause intraoperative femoral fracture or can result in the need to fix the fracture in an extension malreduction [(18)].

2- Interlocking Screw/Bolt Biomechanics

Interlocking screws or bolts are recommended for most cases of IM nailing. The number of interlocks used is based on:

- Fracture location
- Amount of fracture comminution
- The fit of the nail within the canal

Midshaft transverse femoral fractures have the greatest fixation stability because of isthmic cortical contact. Oblique and comminuted fractures rely on interlocking screws for stability, as do very proximal and very distal metaphyseal fractures, where the medullary canal widens and is filled with weaker cancellous bone. Interlocking screws placed proximal and distal to the fracture site restrict translation and rotation at the fracture site; however, minor movements occur between the nail and screws, allowing toggling of the bone. Placing screws in multiple planes may lead to a reduction of this fragment toggle; however, this is not always possible in certain locations because of the proximity of neurovascular structures. At times, the dynamization slots in the nail are used to allow fracture compression while limiting rotation (12).

In a clinical study of immediate weight bearing after IM nailing of femoral fractures, ***Brumback et al.*** (19) indicated that stability of fracture depends on the locking screw or bolt diameter for a given nail diameter. Of course, there is a limit to screw size in that too large a hole in the nail will reduce its strength. In general, this limit is 5 to 6 mm for tibial and femoral nails. As a rule, however, nail hole size should not exceed 50% of the nail diameter. Interlocking screws undergo four point bending loads (Fig. 2), with higher screw stresses seen at the most distal locking sites. Thus, screws should be chosen with the largest root diameter possible; this has led to the use of partially threaded screws, which have a solid body with threads only on the end.

In general, one distal screw is sufficient for stable fractures. The closer the fracture is to the distal locking screws, the less cortical contact the nail has, which leads to increased stress on the locking screws [20].

Additionally, the farther the distal locking screw is from the fracture site, the more rotationally stable the fracture becomes because of friction of the nail within the medullary cavity [21].

The location of the distal locking screws affects the biomechanics of the fracture, but the effect of the orientation of the locking screws is less clear. Orientation of the proximal femur locking screws has little effect on fixation stability. with both oblique and transverse proximal locking screws showing equal axial load to failure. Two screws can be inserted at angles to the cross-section of the nail to decrease motion between the screws and the nail, but anatomic structures must be taken into consideration when performing this technique [22].

3- Biomechanics of IM Reaming

IM reaming can act to increase the contact area between the nail and cortical bone by smoothing internal asperities. When the nail is the same size as the reamer, 1mm of reaming can increase the contact area by 38% [11].

Increased reaming allows insertion of a larger-diameter nail, which provides more rigidity in bending and torsion. Biomechanically, reamed nails provide better fixation stability than do unreamed nails. Despite these advantages to reaming, the process has some biomechanically deleterious effects on the bone itself. Depending on the outer diameter of the bone and the amount of bone removed, reaming of the canal diminishes the cortical wall thickness and can weaken the bone. The effect of inner cortical thinning can be mitigated with nail insertion because the nail will carry part of the load [(23)].

4- Other Factors Affecting Nail Biomechanics

The starting point for insertion of femoral nails can have significant consequences on the ease of nail insertion as well as the strength of the resulting fixation. When the femoral head is compressively loaded in cadaveric femurs, the load to failure is affected more by nail starting point malposition than by increased nail size [(24)].

Placing the starting point too anterior from the piriformis fossa (6 mm) creates a major risk of proximal femoral bursting with nail insertion (Figure 3). The risk is lower for medial and lateral malpositioning [(24)].

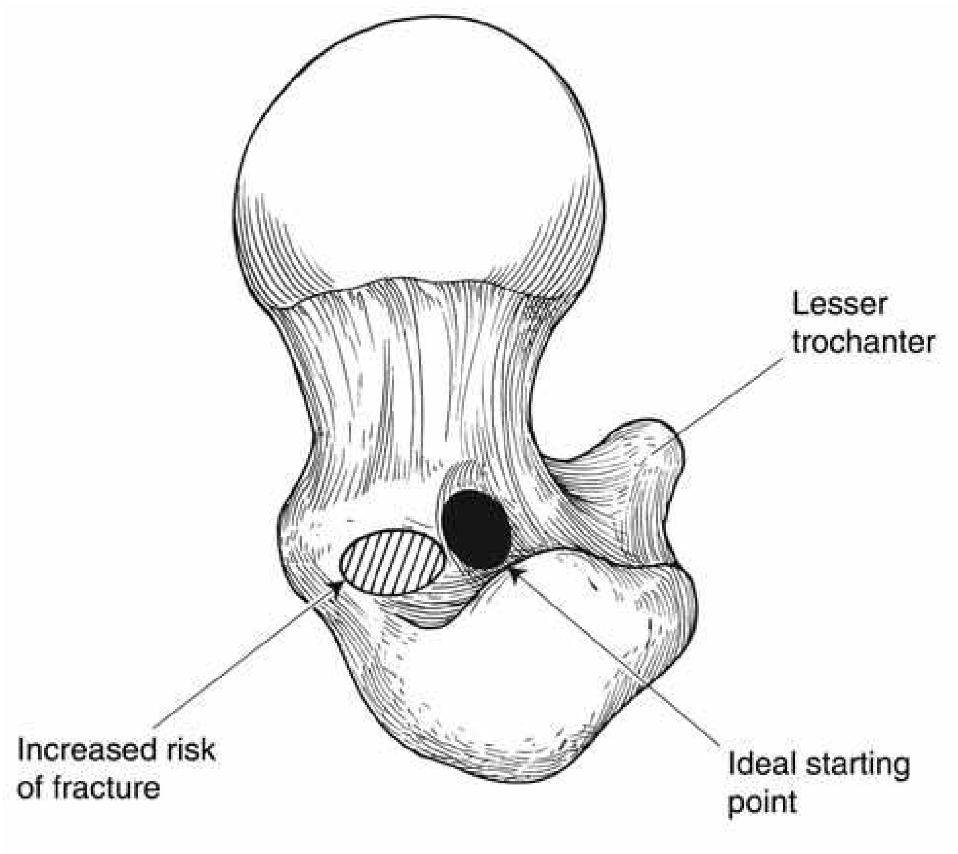

Fig. (3): The ideal starting point for insertion of an antegrade femoral nail is in the posterior portion of the piriformis fossa. Anterior placement of the starting hole places the proximal femur at increased risk of intraoperative fracture [24].

To maintain optimal alignment in nondiaphyseal fractures, care should be taken to direct the nail into the center position of both fragments. In addition, multiple locking screws should be used in the metaphyseal fragment. The placement of blocking screws can aid in aligning nondiaphyseal fractures of the femur. Blocking screws also can improve the primary stability of the fixed fracture [25].

5- Weight Bearing After Reamed IM Nailing

Current recommendations regarding weight bearing after IM nailing of diaphyseal femoral fractures are based on the work of ***Brumback et al.*** [19]. These authors created a model of a segmentally comminuted diaphyseal femoral fracture without bony contact and found that nails with a 12-mm diameter and two distal locking bolts could withstand the typical biomechanical forces of weight bearing. Their clinical results supported this biomechanical finding. In patients who retain diaphyseal bony contact after fracture fixation, nails with a diameter <12 mm or nails with a single distal interlock may provide adequate stability for weight bearing because the bony contact reduces the load encountered by the distal interlocking screws.