Biomechanics of Intermedullary Nail

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Evolution

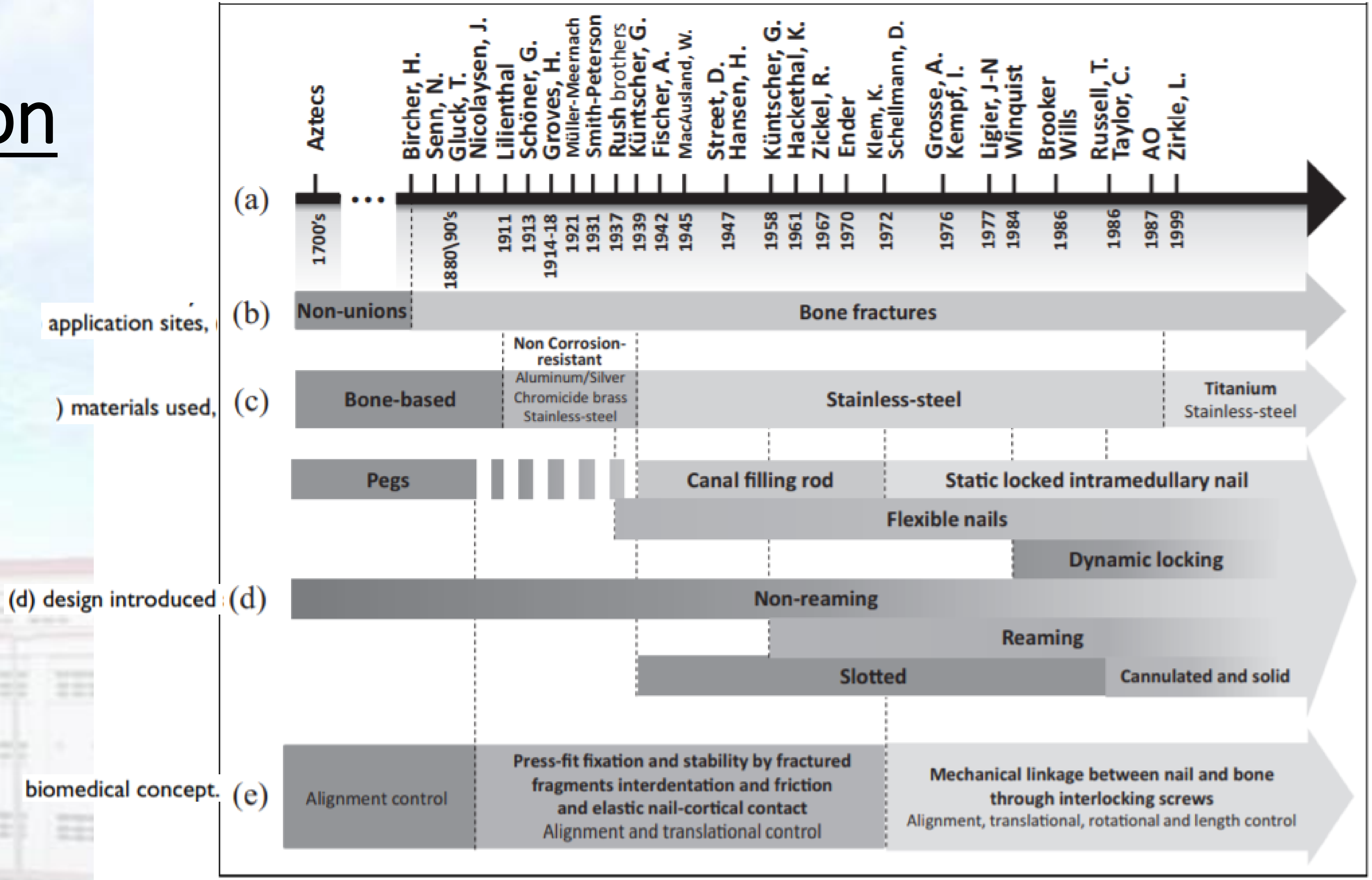


Figure 1. Schematic chronological representation of the turning points in the evolution of the intramedullary fixation, from the 16th century and up to the 20th century. Information is arranged according to (a) timeline, (b) application sites, (c) materials used, (d) design introduced and (e) biomedical concept.

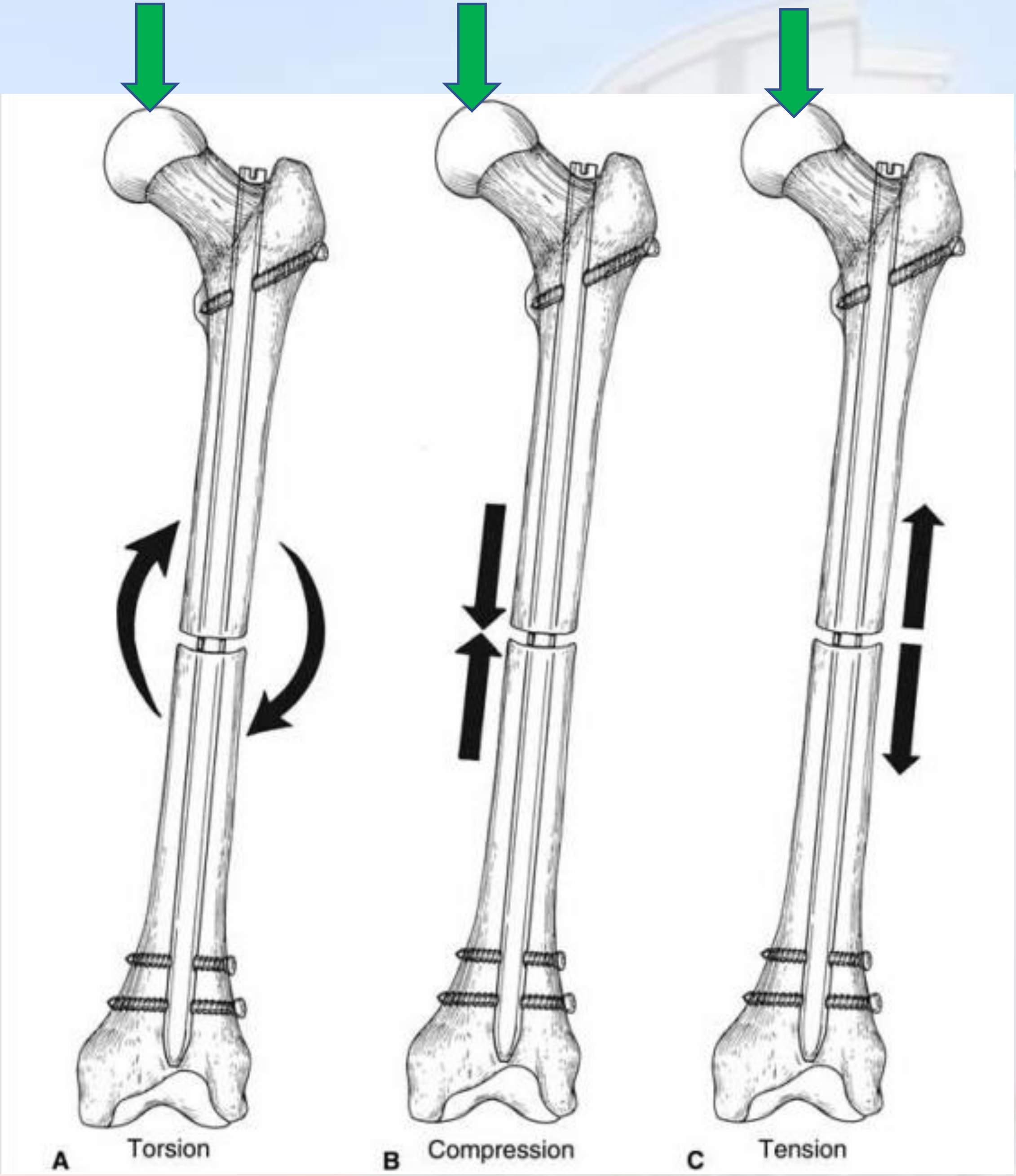
Biomechanics of IM nail

- Internal splints with load-sharing characteristics

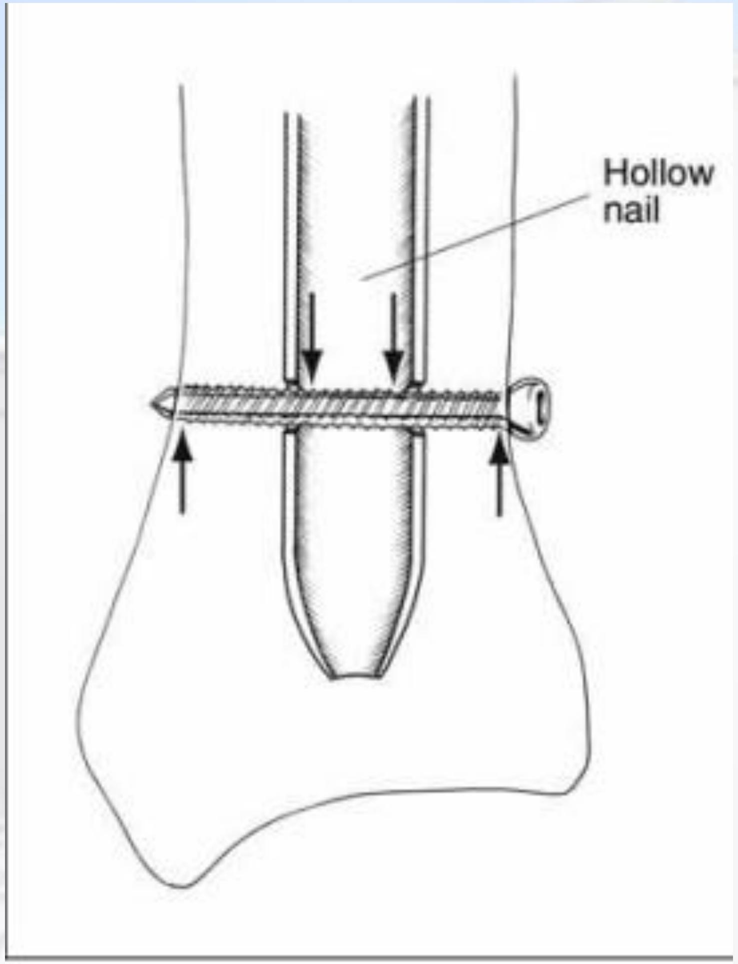
- The amount of load borne by the nail depends on the stability of the fracture/implant construct which determined by:
  - nail size
  - number of locking screws or bolts
  - distance of the locking screw or bolt from the fracture site

- gradually transfer it to the bone as the fracture heals

- Three types of load act on an IM nail:
  - Torsion
  - Compression
  - Tension
- 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



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.

Factors Affecting Stiffness Of The Nail:

- material properties
- cross-sectional shape
- diameter
- degree of anterior bow of the femoral nail

1. Material properties

- Young modulus
- Titanium vs stainless steel
- stainless steel nails had 25% more torsional rigidity than did the titanium alloy version, their ultimate strengths were similar
- Nett conclusion = equal

2. Cross section

- Slotted vs non slotted
- Important before the intro of locking screws
- Torsional rigidity : Locking screws > slotted > non slotted

- Without interlocking screws, the friction of the nail within the medullary cavity determines this resistance to motion.
  - Nail curvature
  - Cross section
  - Diameter
  - Canal properties (size, shape, bone quality)

Slotting

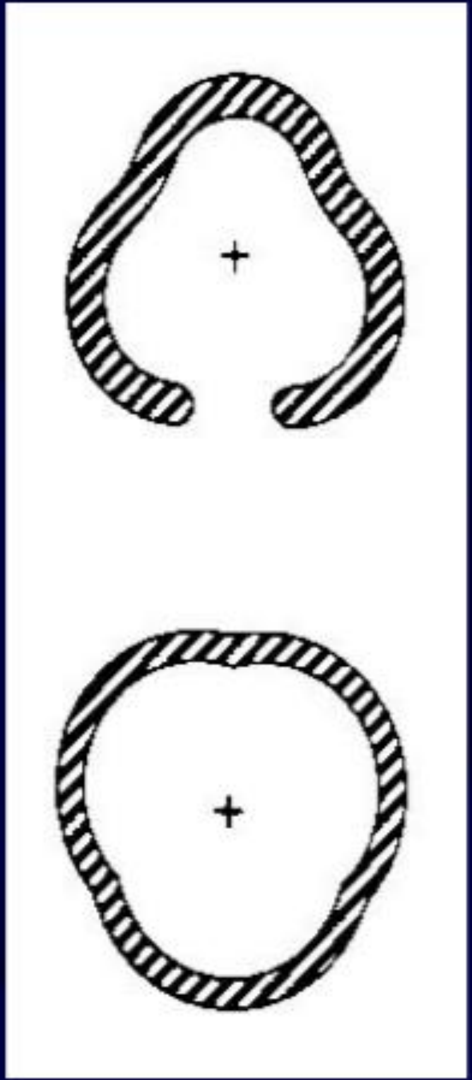


Figure from: Tencer et al, Biomechanics in Orthopaedic Trauma, Lippincott, 1994.

- Allows more flexibility
  - In bending
- Decreases torsional strength

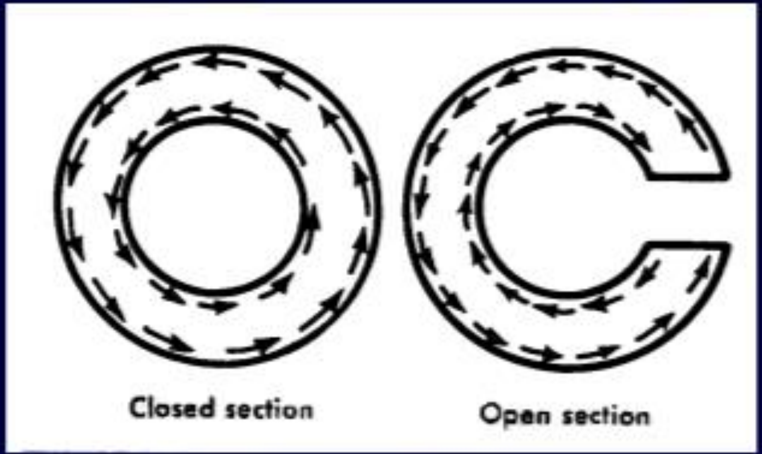


Figure from Rockwood and Green's, 4th Ed

3. Nail diameter

- Solid circular nail
  - →bending rigidity proportional to r3
  - →torsional rigidity proportional r4

- Diameter also affects nail fit
  - a well-fitting nail can help reduce movement between the nail and bone and maintain fracture reduction

IM Nails
Moment of Inertia

- Stiffness proportional to the 4th power.

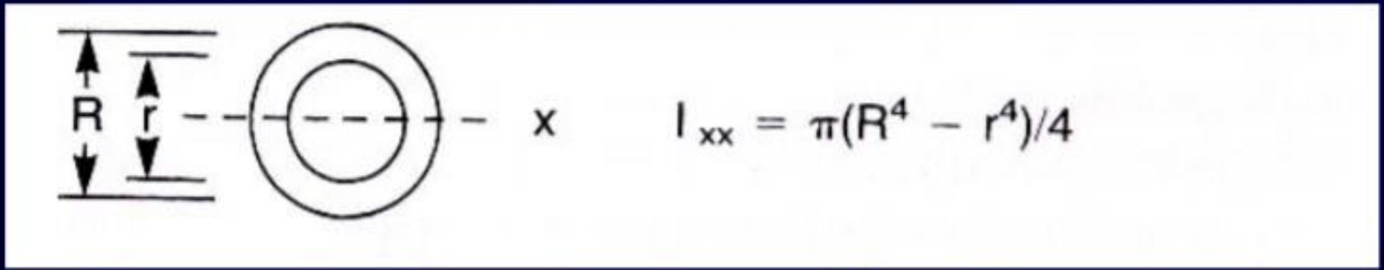
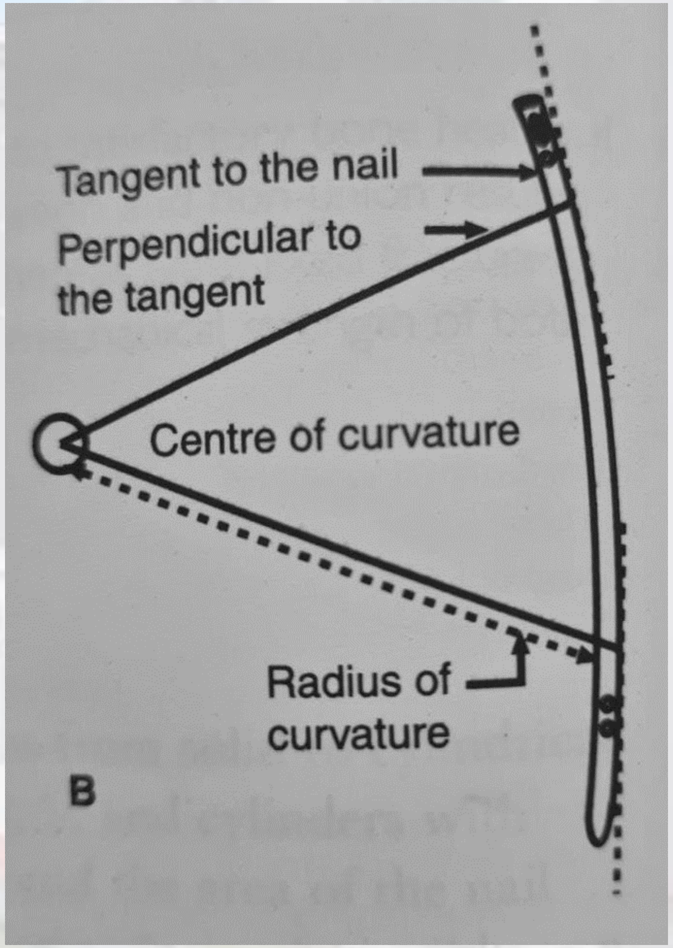


Figure from: Browner et al, Skeletal Trauma, 2nd Ed, Saunders, 1998.

4. Degree of anterior bowing of the nail

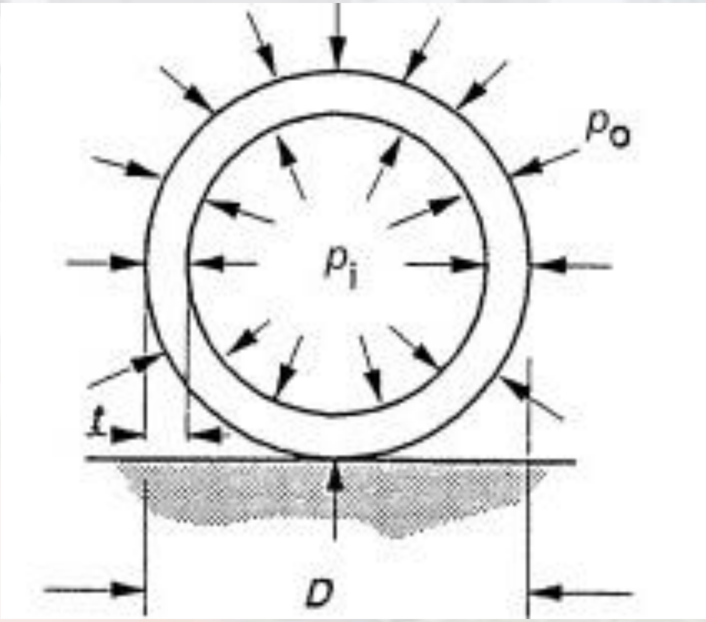
- average radius of curvature of the human femur is 120 (±36) cm
- Nails with a smaller radius of curvature mismatch are easier to insert but have less frictional fixation and vice versa
- Insertion of nails with a large mismatch of curvature with the bone can cause intraoperative femoral fracture or can result in the need to fix the fracture in an extension malreduction



- During the insertion of the nail, axial force is necessary –
  - Force is max at 3/4 of the insertion length then lesser as the nail follows the femur curvature

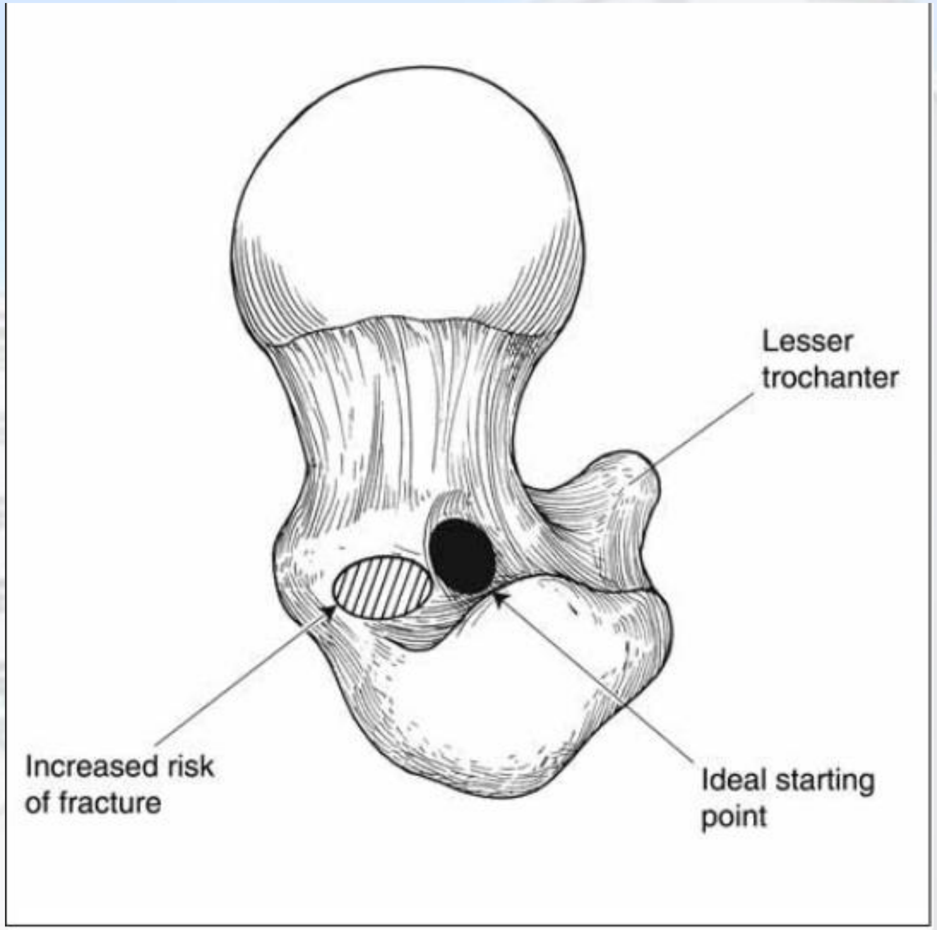
  - Insertion force = generates hoop stress (circumferential expansion stress)
  - >>> hoop stress = split femur fracture/making the fracture more comminuted

  - To reduce hoop stress :
    - Over reaming entry hole
    - Shorter length of the fracture fragments
    - Most important : nail entry point!



Nail Entry Point

- Placing the starting point too anterior from the piriformis fossa (≥6 mm) creates a major risk of proximal femoral bursting with nail insertion because of increased hoop stresses
  - Aim is central axis of the canal
  - Medial lateral plane : junction of femoral neck and GT (depends on the nail design entry point)



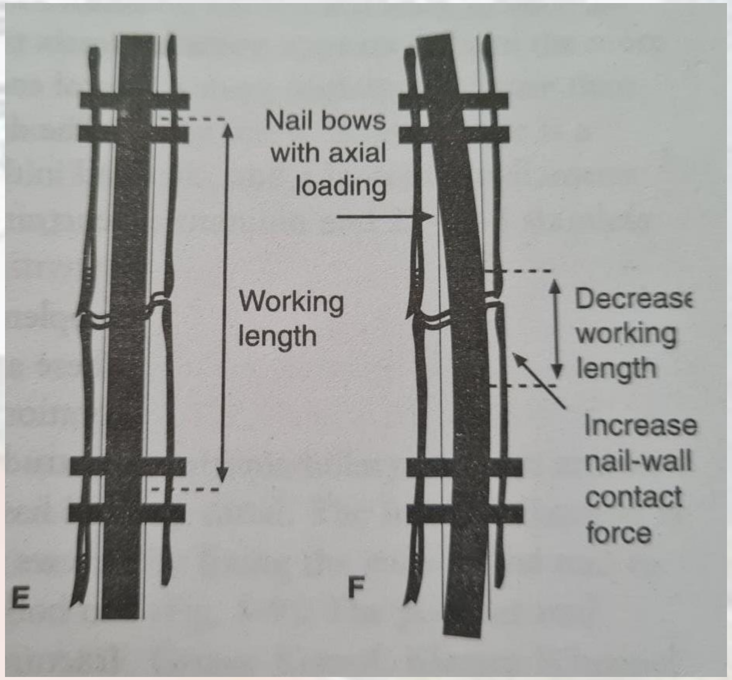
The ideal starting point for insertion of an antegrade femoral nail is in the posterior portion of the piriformis fossa. Anterior placement of the starting hole places the proximal femur at increased risk of intraoperative fracture.

Length and working length

- Consideration :
  - Total nail length
  - Length of nail-bone contact
  - Working length

- Total nail length : anatomical, too long will cause nail protrusion at entry site, too short, will compromise fixation
- Length of nail-bone contact : surface contact
  - Higher contact area, higher resistance to motion

- Working length :
  - Length of a nail spanning the fracture site from its distal point of fixation in proximal fragment to its proximal point of fixation in distal fragment.
  - Unsupported portion of the nail = reflects the length of nail that carries majority of the loads
  - Bending stiffness = inversely proportionate with square of its working length
  - Torsional stiffness = inversely proportionate with its working length
  - Shorter working length = stronger fixation
  - Factors that can modify the working length :
    - Interlocking screws
    - Medullary reaming

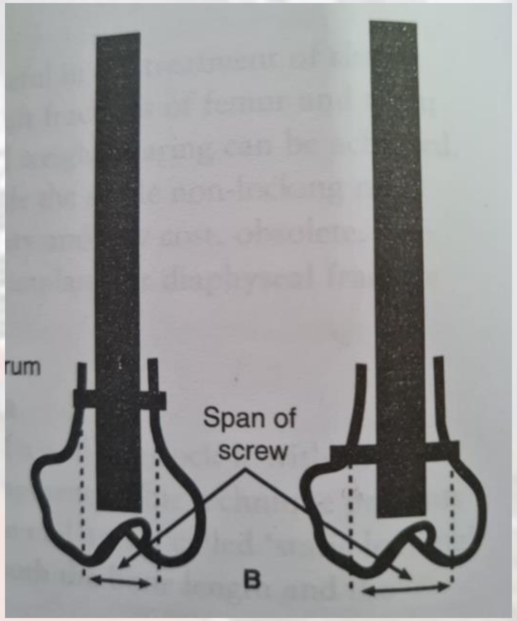


Interlocking Screws/Bolts

- How much to put will depends on:
  - fracture location
  - amount of fracture comminution
  - fit of the nail within the canal
- 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
- 2 distal screws should be inserted if length of distal fragment < 60% of length of midpoint of shaft to joint line.

- stability depends on the locking screw diameter for a given nail diameter (but must be balance with the risk of broken nail due to nail hole diameter – stress riser)
- As a rule, nail hole size should not exceed 50% of the nail diameter
- Two screws can be inserted at angles to the cross-section of the nail to decrease motion between the screws and the nail
- Increase span of screw also reduce stiffness

  and strength of the screw



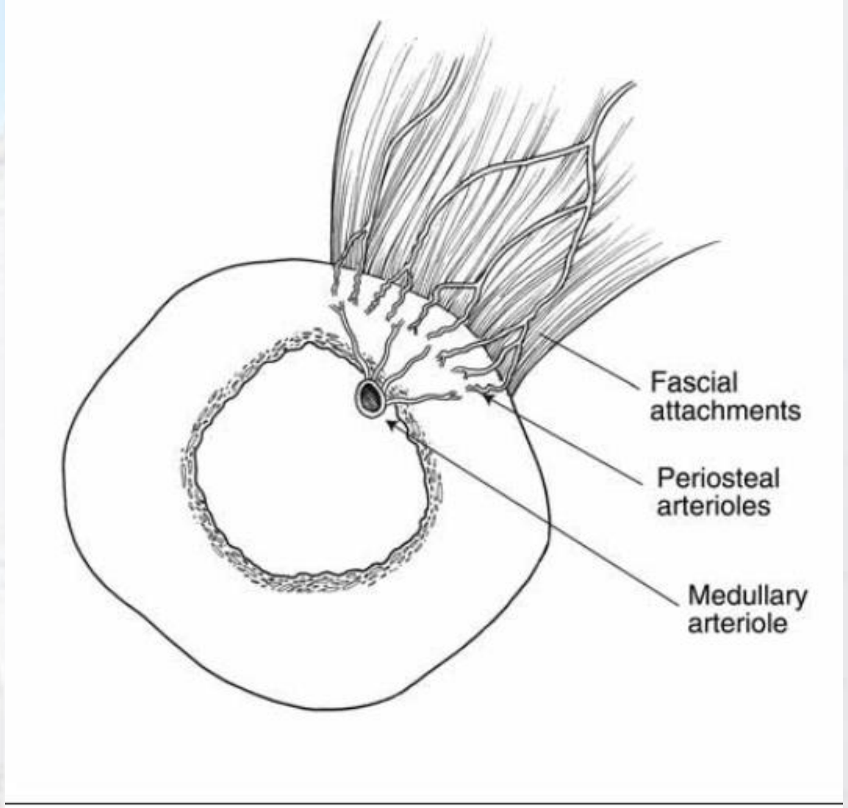
- Dynamization :
  - Removed screw at longer fragment, to maintain adequate control of shorter fragment
  - Avoid premature removal of locking screws : shortening, instability, non union

Intramedullary Reaming

- Reaming more stable, as may increase nail size and fitting of nail to the canal

BONE BIOLOGY

- Blood supply of cortical bone



Cross-sectional view of a long bone. Fascial attachments are the entry points of periosteal arterioles. These periosteal arterioles provide the blood supply to the outer third of the cortex and anastamose with medullary arterioles.

Effect of reaming

- Destroy medullary canal content and endosteal supply of the bone
- But studies has showed :
  - reaming significantly increases the vascular perfusion of surrounding muscles and deep soft tissues
  - local effect of reaming is the deposition of autologous medullary contents and osteoinductive factors at the fracture site.

- ?intracompartmental pressure while reaming
  - no difference in peak compartment pressures during insertion of IM nails with and without prior reaming

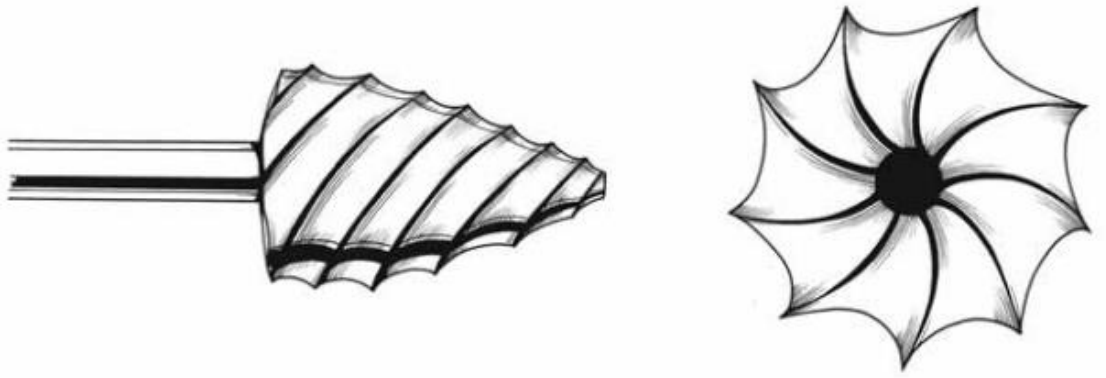
Table 5-1 Intramedullary pressure changes during nailing

Activity	Appliance	Femur	Tibia
Opening of medullary cavity	Awl	Insignificant rise	Insignificant rise
	Cannulated cutter	Significant rise	Insignificant rise
Insertion of guide wire	Guide wire	Significant rise	No data available
Insertion of reamer	Fast insertion	Significant rise (much less than in the tibia)	Significant rise (far greater than in the femur)
	Slow insertion	Insignificant rise	Insignificant rise
Insertion of nail	Hollow nail	Minor rise	Minor rise
	Solid nail	Same as reamed (hollow) nail	Significantly lower pressure than reamed (hollow) nail
Inserting distal vent		No change in pressure readings	No data

- Systemic effect : bone marrow infiltration to the circulation
  - It may cause embolization to pulmonary circulation, however the effect on it is yet to be determined

Reamer design

- Reamer characteristics that can lower peak IM pressures include a narrow reamer shaft, sharp cutting flutes, deep flutes, and a conical shape



This reamer design minimizes increases in intramedullary pressure. Note the narrow reamer shaft, sharp cutting flutes, deep flutes, and conical shape.

- Reamer with suction reduce the pressure while reaming and reduce marrow embolization (animal studies)

Reamed in open vs closed fracture

- Postulation : in the setting of a fracture where local soft tissues are traumatized and the extraosseous blood supply has been diminished, reaming would eliminate the remaining blood supply, thus predisposing the fracture to infection
  - But : clinical studies has shown no difference in the infection rate between nails placed with and without prior reaming in open fractures
- 4.5 times greater relative risk for the development of nonunion with unreamed nails
- No significant clinical results on reaming in open vs close fracture

- Thank you
- Good luck in your exam!