Introduction to the Biomechanics of Fracture Fixation

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Introduction

- **Clinical goal of effective fracture treatment**
  - To induce rapid haling without significant deformity of limb shortening
    - For elderly → rapid healing is very important to prevent long bed rest
    - Fracture stabilization → determined by the location, type of fracture, the muscle & body forces, ligament conditions
  - To restore the patient to a pre-fracture level of function

- Traditional methods for the treatment of fractures → external application
  - Traction, casts, and braces
  - To limit muscle or soft tissue forces leading to deformity
  - To maintain alignment

Fracture Healing

- Controversy → Is completely rigid fixation the best?
  - Micromotion → bone growth → bone healing
  - Too rigid → delayed healing, → bone atrophy

- Motion (strain) near healing → <u>fibrocartilage</u> or <u>bone</u>
  - <u>Gross Motion → usually leads to nonunion & fibrocartilage tissue formation</u>
  - <u>Micromotion → mechanical signal → stimulates the biological repair process → bone growth → bone healing</u>
  - Frequency, wave form, and total number of cycles → still areas of investigation

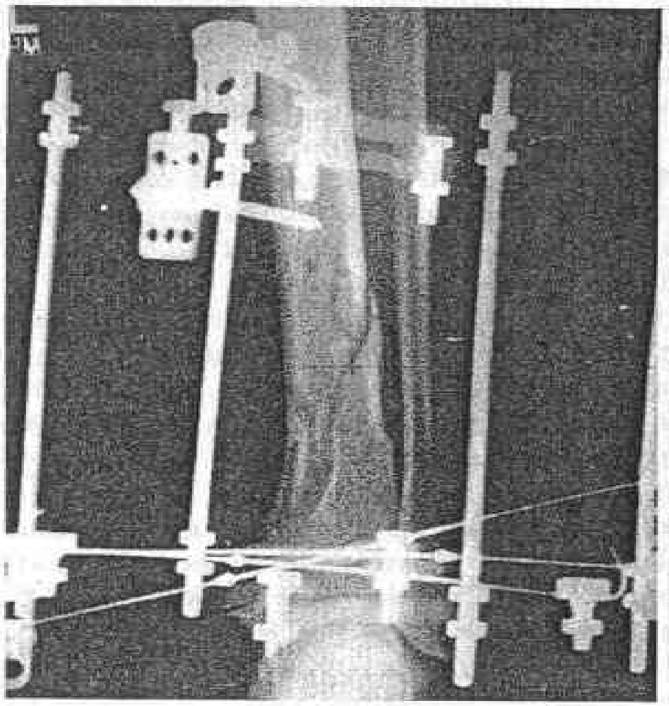
- Also, ultrasound or electromagnetic fields → aid bone healing
- If too much load is carried by the fixation device → stress shielding → unloading of bone → bone resorption (by Wolff's Law)

CASE STUDY 15-1

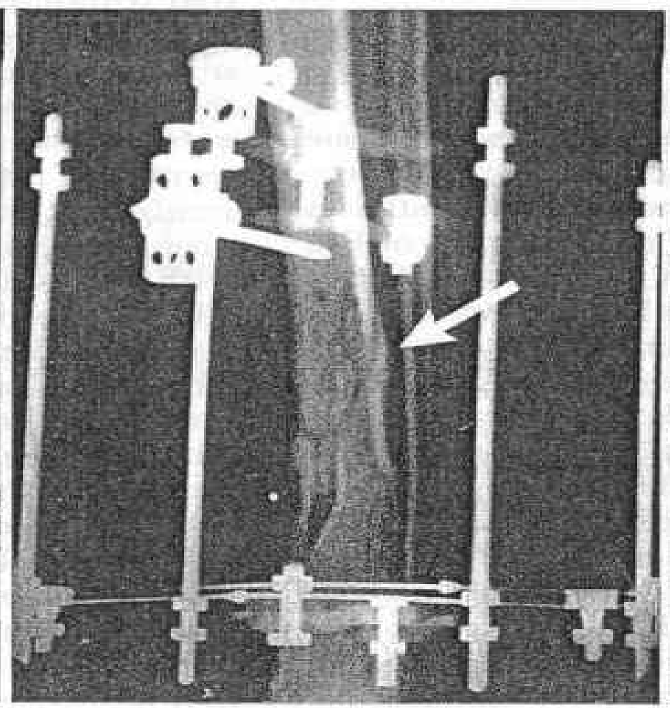
Ultrasound Treatment for Fracture Healing

A 40-year-old female involved in a motor vehicle collision in December sustained a left tibiofibular fracture treated with external fixation. Case Study Fig. 15-1-1, in January, low-intensity pulsed ultrasound (US) was initiated to promote fracture healing. Case Study Fig. 15-1-2, in March, 3 months postfracture and 2 months after initiation of pulsed US application, early healing is detected (arrow). Case Study Fig. 15-1-3, in May, 5 months after injury and 4 months following initiation of US, the bone healing is successful.

Pulsed low-intensity ultrasound has been successfully used for fracture repair (Frankel, 1998). Ultrasound is an acoustic radiation at frequencies above the limit of human hearing. Its acoustic radiation, in the form of pressure waves, provides micromechanical stress and force to the bone and surrounding tissue. This mechanical stimulation plays a major role in bone healing because bone reacts to the amount and direction of force and remodels to adapt to the applied stress and its direction. Reprinted with permission from Wolff, J. (1986). *Das Gesetz der Transformation der Knochen* [The law of bone remodeling]. P. Maquet & R. Fulong (Trans.). Berlin: Springer-Verlag. (Original work published in 1892).



Case Study Figure 15-1-1.



Case Study Figure 15-1-2.

Case Study Figure 15-1-3.

- Bone healing process after fracture (gap)
  - Haematoma & inflammation → callus formation, replacement by woven bone → remodeling into lamellar or trabecular bone
  - Callus → less strong & stiff than mature bone → but, enlarges the diameter of the bone at the fracture site → moment of inertia ↑ → bending & torsion strength ↑

- Direct apposition by rigid fixation → too much compression → initial repair process ↓ → delay
- adequate blood supply → early revascularization → good bone healing

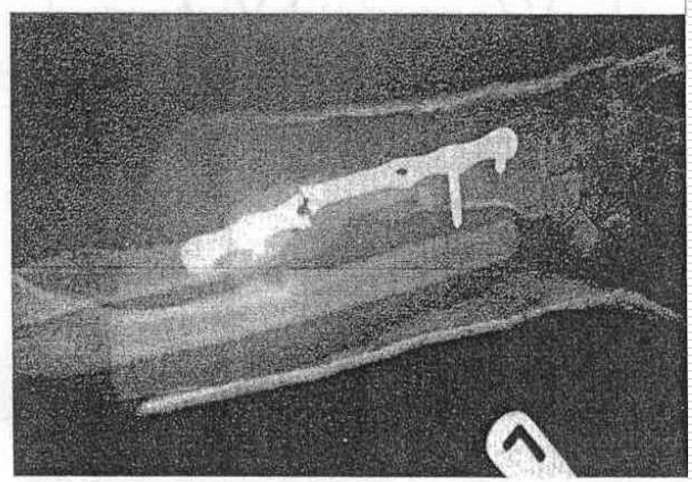
Surgical Factors

- mechanical considerations
  - Load types
    → tension, bending, and/or torsion
  - Magnitude
  - Number of load, fatigue (Case 15-2)

CASE STUDY 15-2

Fixation Plate Failure

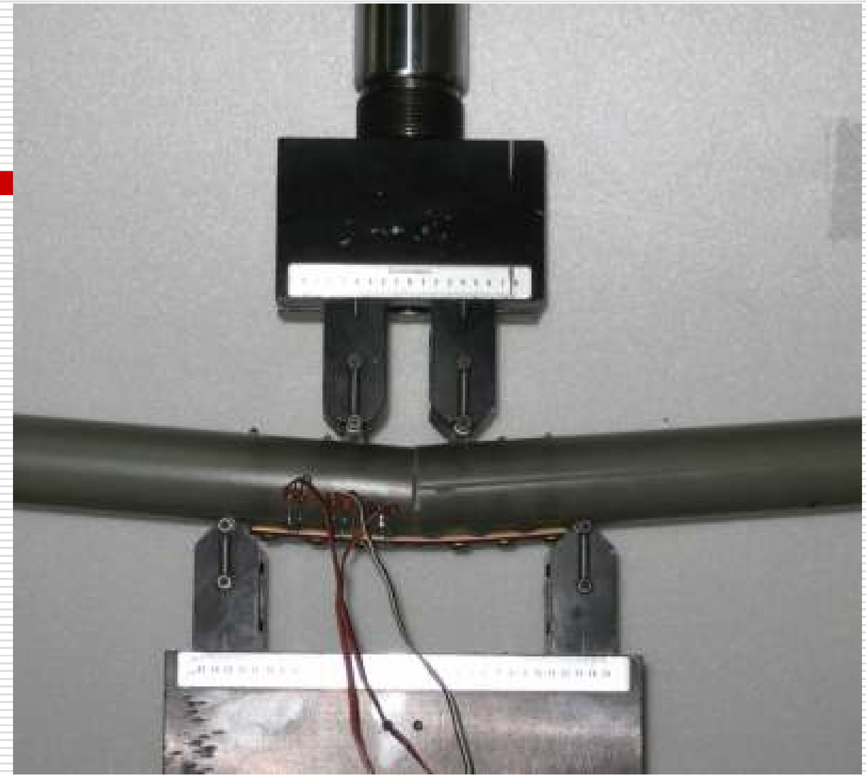
An internal contemporary fixation plate inserted into the arm of a 25-year-old male who sustained a fracture of the radius. The plate was fractured as a result of fatigue 20 years later. Repeated loading and unloading of a material will cause it to fail, even if the loads are below the ultimate stress (Simon, 1994). Each loading cycle produces a minute amount of microdamage that accumulates with repetitive loads until the material fails. Mechanical considerations as to the magnitude and repetition of the loads to which the fixation will be subjected should be considered, along with the fatigue life of the material. This is recorded on a curve of stress versus number of cycles. Thus, higher stresses produce failure in fewer cycles (loading to the ultimate stress produces failure in one cycle), while lower stresses are tolerated for an extended period.



Case Study Figure 15-2-1.

- Patient consideration → bone quality
- Surgical considerations→ exposure level → neurovascular structures, scarring, device fit, etc
- Evaluation of fixation strength
  - experiment → can be done with cadaver bone with actual implants

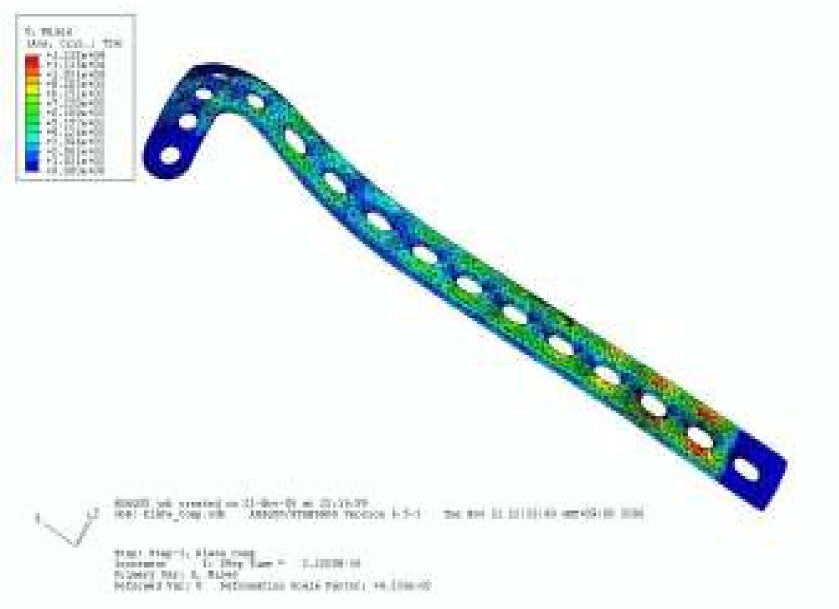
CHS compression test

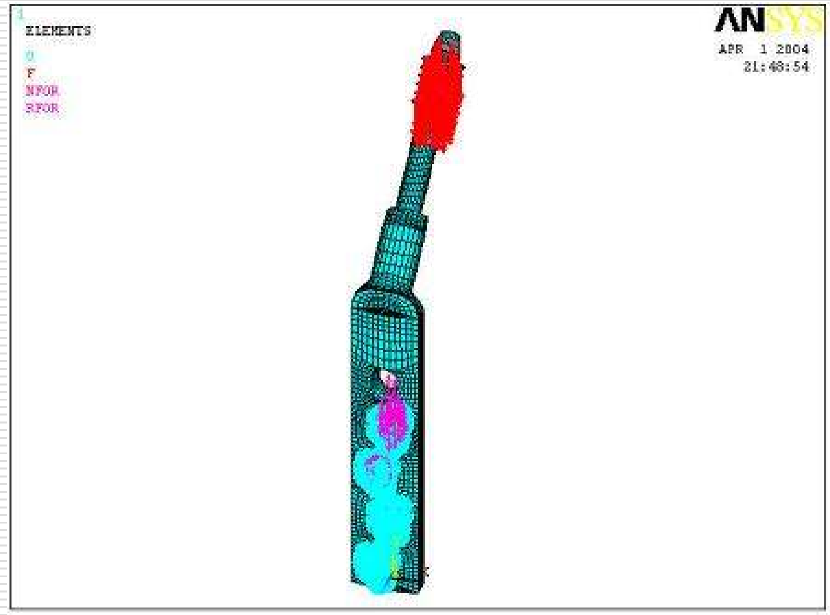


LC-DCP bending test

Limited contact dynamic compression plate

- computer modeling → finite element study





ABAQUS

ANSYS

- clinical trials

- Fixation Devices & Methods

Devices

- Types → wires, staples, pins, plates, screws
- Materials
  - Stainless steel (316L)
  - Titanium alloy (Ti6Al4V)
  - CoCr alloy

- Biodegradable polymers (polylactic acid, PLA)
  - More flexible than metals
  - Degradation over time during healing process → no stress shielding → better load bearing after degradation
  - No secondary operation
  - But, problems still exist with degradation time and mechanical strength

wire fixation

- Most common
- problems → loosening, bone holes, breakage, cut-through of the bone
- Recent development with wiring instrumentation
- Staples

Krischner wires

- To hold the bone fragments together before rigid fixation
- Not enough strength
- With wires
- Threaded pins
  → better strength,
  but difficult to remove

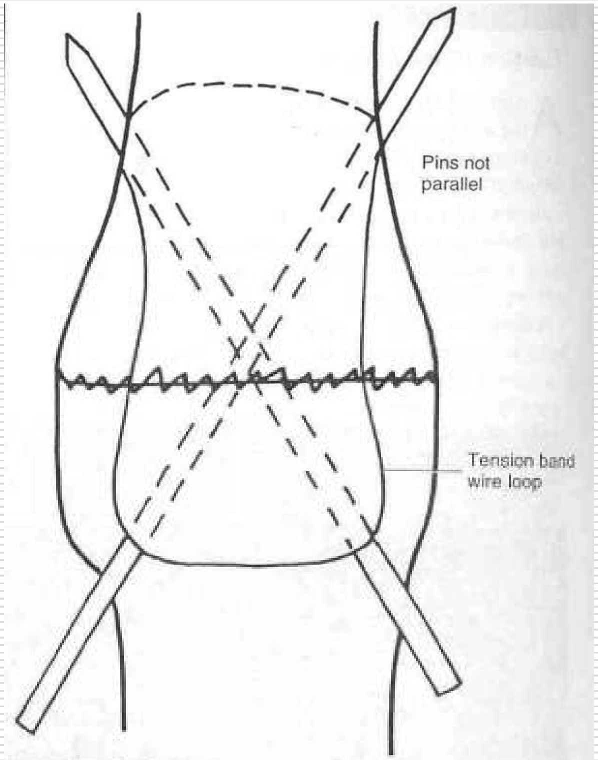


FIG. 15-1

Tension band wiring of two K-wires; tightening the wire loop applies compression to the fixation. K-wires are inserted in a skewed configuration for stability.

Screws & Plates

- screw parameters
- two basic types of screws
  a. Cortical
  b. cancellous → longer pitch, higher outer/root diameter ratio
  c. cancellous lag → no threads in the proximal region, larger diameter

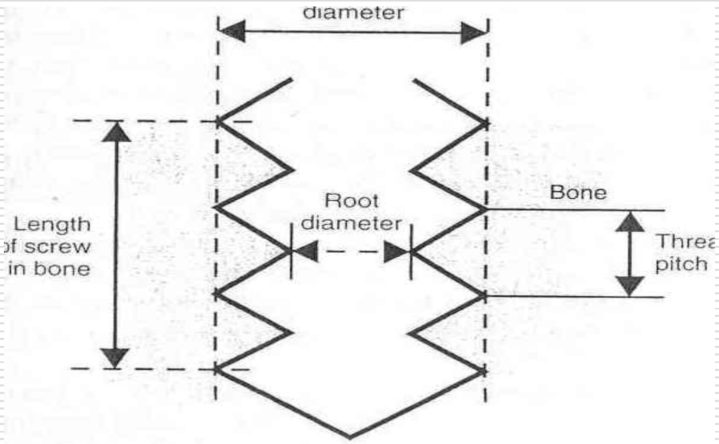


FIG. 15-2

Screw parameters. For screw pull-out the bone must she along the outer diameter (*dotted line*).

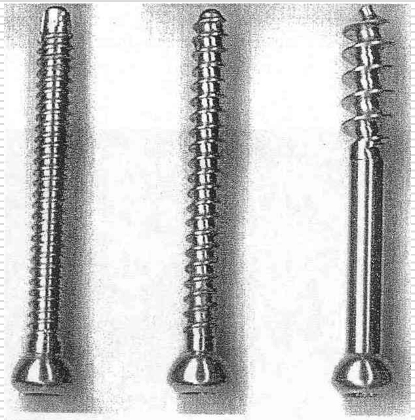


FIG. 15-3

Types of bone screws. Left to right: cortical, cancellous, and cancellous lag.

- Various factors
  - Holding power = f (outer screw diameter X threaded length within the bone)
  - Insertion torque
    → determines the force with which bone fragments are held together
  - Insertion direction
    → if not perpendicular to fracture → not so optimal
  - Pre-tapping, self-tapping
  - Friction with bone
  - Bone quality
  - cortical purchase → bi-cortical or uni-cortical?
  - Anatomical constrains
    → limits the number or size of the screw

- With plates (Fig15-4)
  - to achieve stability & increase strength of fixation
  - location of plate (Fig15-5)
  - screw hole slots
  - pre-bending of plates
  - plates with bone graft to close the gap

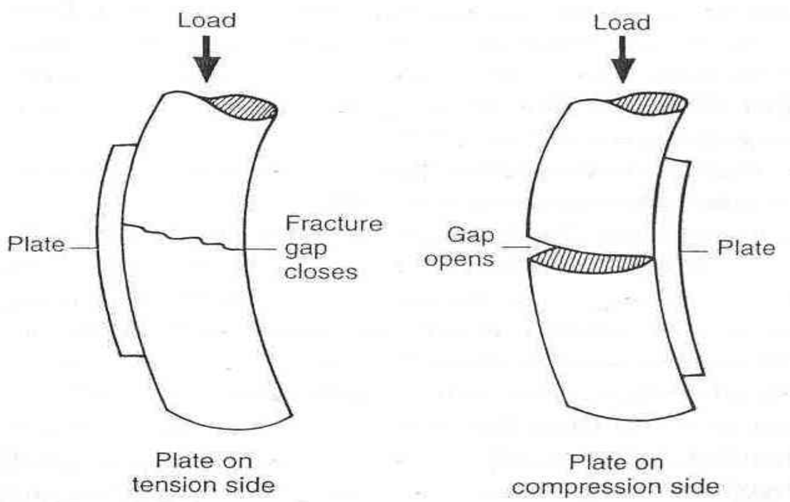


FIG. 15-4

Effect of plate placement. A plate located on the compression side causes the fracture to gap when loaded.

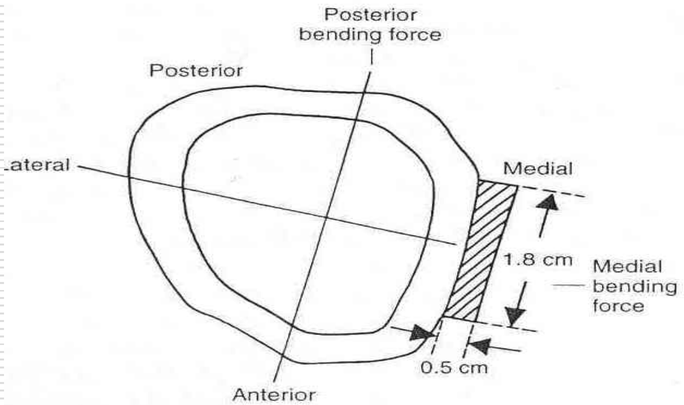


FIG. 15-5

Effect of loading direction on plate stiffness. The rigidity of the plate is EI, where E is the modulus of the plate material and I is the moment of inertia of the plate. $I = bh^3/12$ (I_1 = posterior bending; I_2 = medial bending; $I_1 = 0.5 \times 1.8^3/12 = 0.243$; $I_2 = 1.8 \times 0.5^3/12 = 0.01875$), where b is the base dimension and h is its height. Thus, the plate is 13 times more rigid in posterior bending than in medial bending.

- hip fracture devices (Fig15-6)
  - stress distribution within the bone and device → influences fracture healing and device survival
  - internal device (IM nails)
  - external device (hip screws with side plate)
  - comparison of loading (Fig 15-7): the external device → higher bending moment → higher compressive stress at the medial side
  - diameter is very crucial → I ∝ r 4

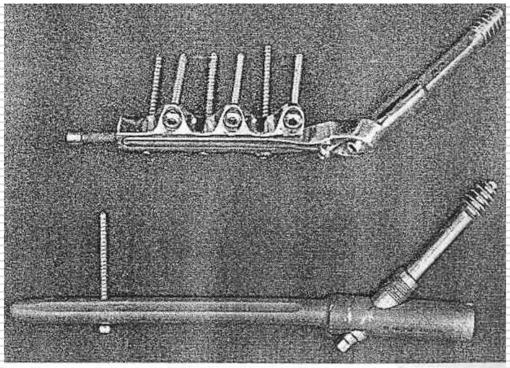


FIG. 15-6

Typical intermedullary and extramedullary devices. *Top,* Medoff sliding plate; *bottom,* intermedullary hip screw.

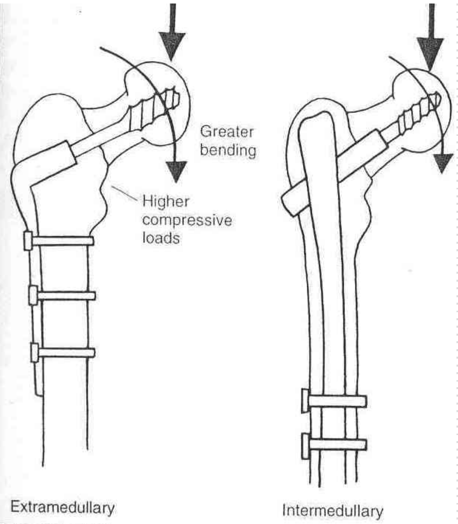


FIG. 15-7

The extramedullary device is less rigid and when loaded has greater deflection, creating higher medial stresses in the femur.

- external fixation device
  - With multiple transcutaneous pins
  - Bar or ring to stabilize the pins
  - Factors that influence mechanical stability and rigidity → number, diameter, orientation, and length of pins and their relation to fracture

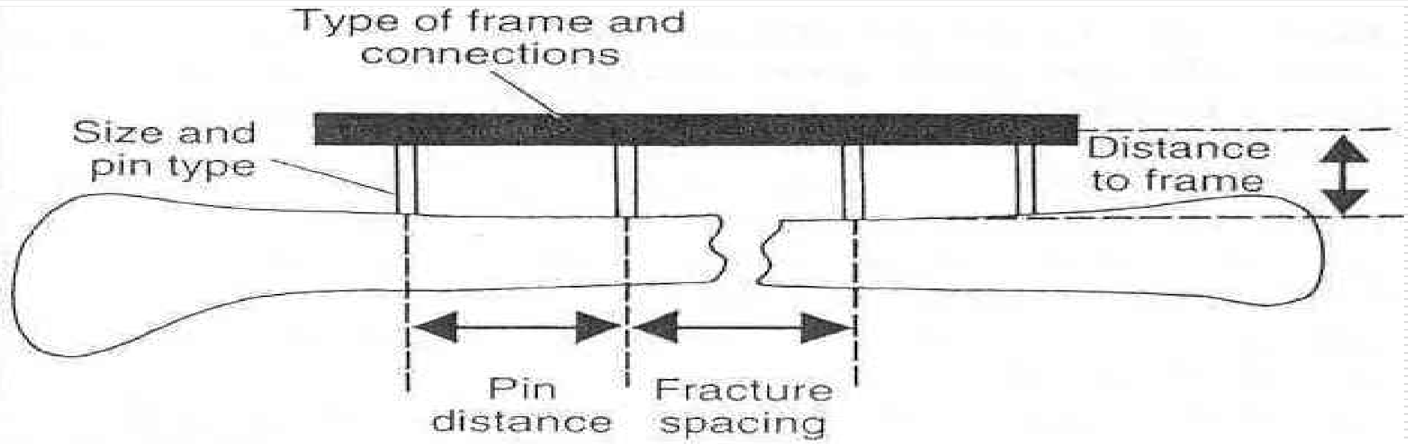


FIG. 15-8

Typical external fixator showing the variable that influences fixation stability.

THANKS