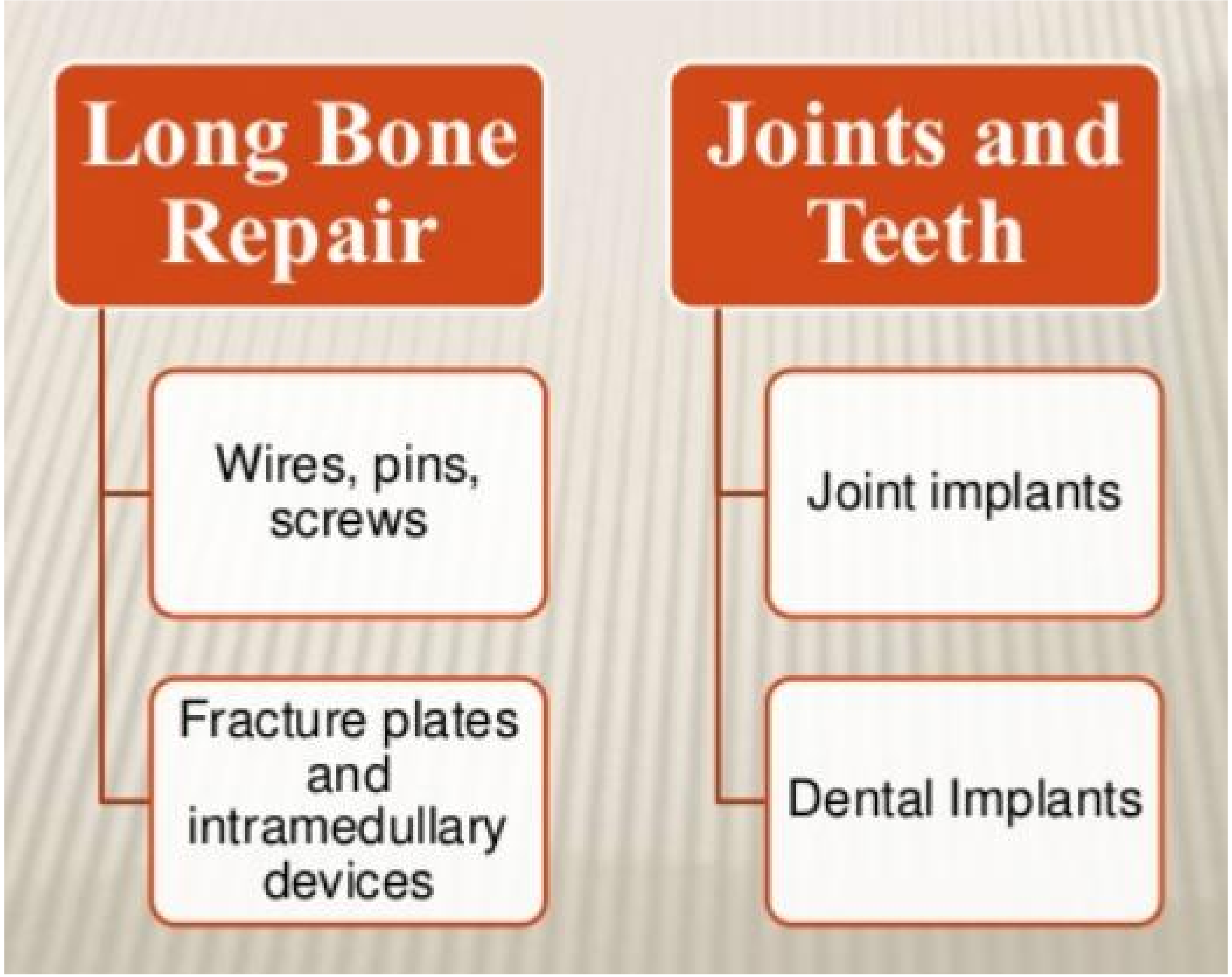
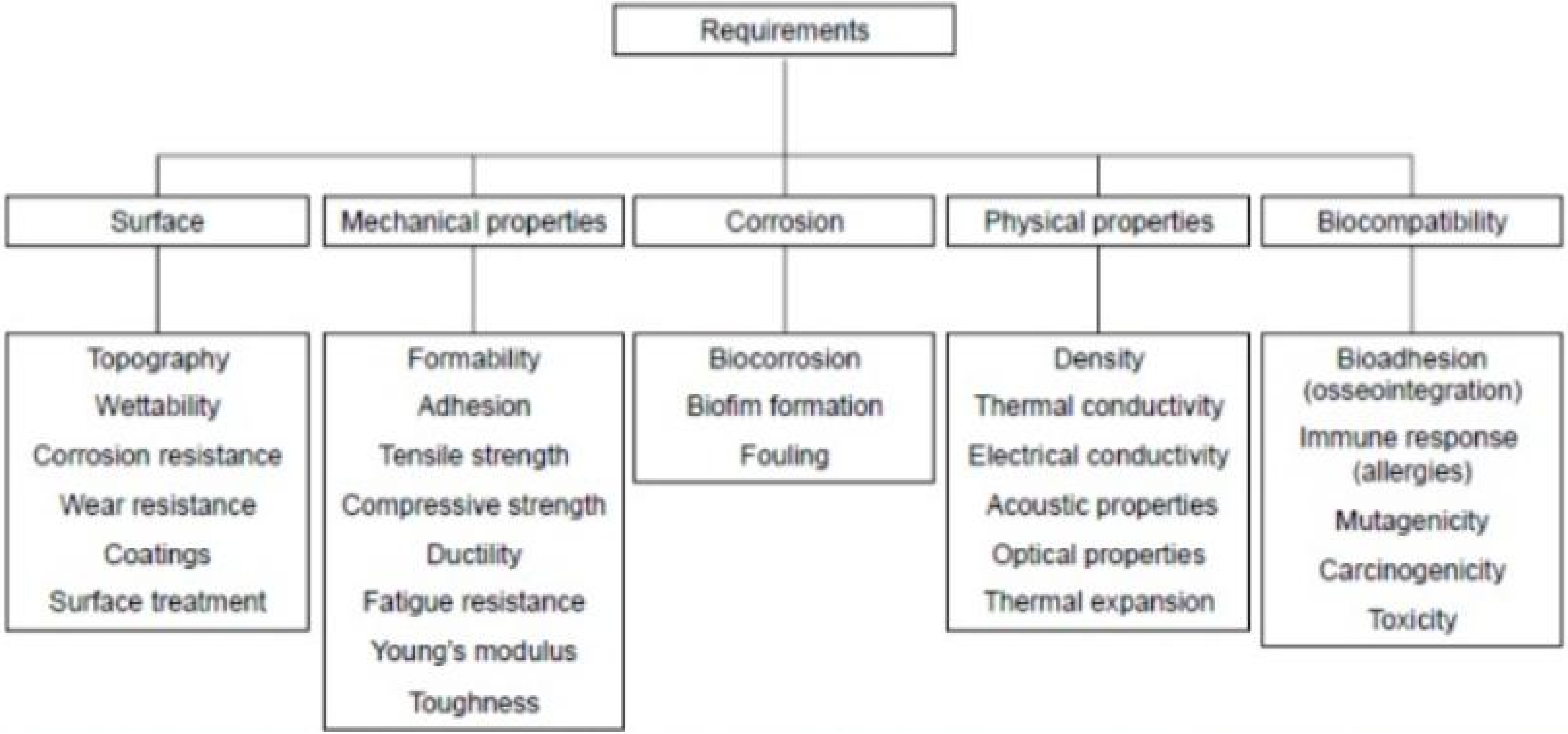
Module 5

Hard Tissue replacement


Long Bone Repair
Wires, pins, screws
Fracture plates and intramedullary devices
Joints and Teeth
Joint implants
Dental Implants


Requirements
Surface
Mechanical properties
Corrosion
Physical properties
Biocompatibility
Topography
Wettability
Corrosion resistance
Wear resistance
Coatings
Surface treatment
Formability
Adhesion
Tensile strength
Compressive strength
Ductility
Fatigue resistance
Young's modulus
Toughness
Biocorrosion
Biofim formation
Fouling
Density
Thermal conductivity
Electrical conductivity
Acoustic properties
Optical properties
Thermal expansion
Bioadhesion (osseointegration)
Immune response (allergies)
Mutagenicity
Carcinogenicity
Toxicity

Long bone repair

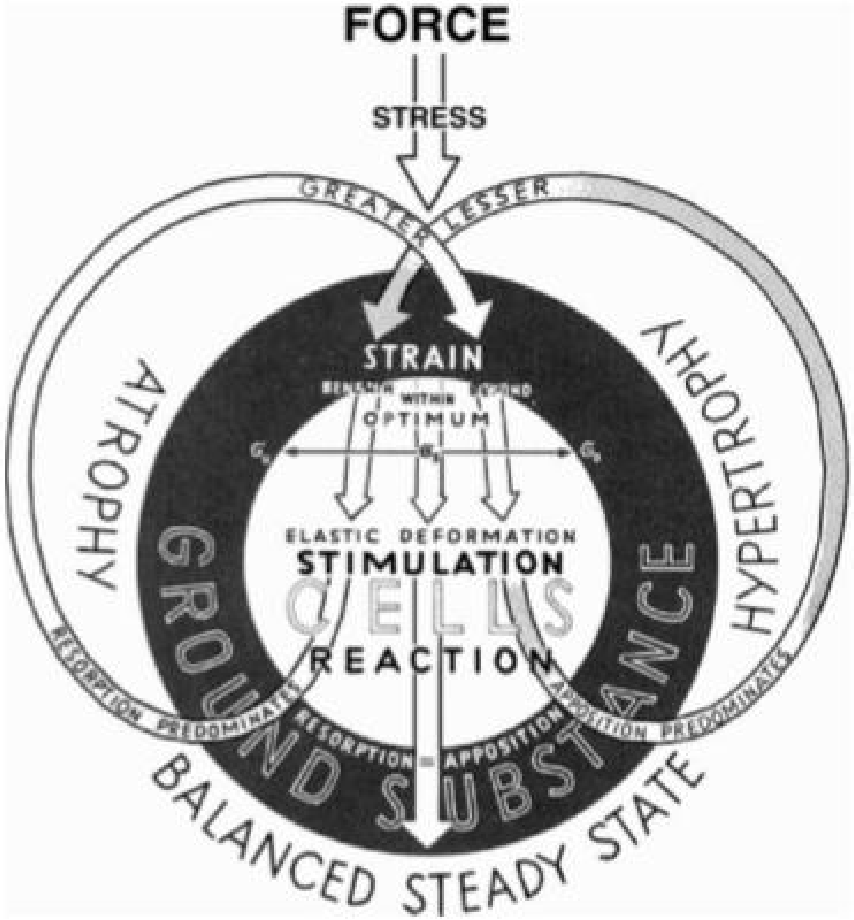
- Wolff’s law of bone remodeling:

Bone can adapt to a new mechanical environment by changing the equilibrium between osteogenesis(bone formation) and osteoclasis (bone removal).These processes will respond to changes in stress applied to bone; that is ,if more stress than the physiological is applied, the equilibrium tilts toward more osteogenic activity. Conversely, if less stress is applied the equilibrium tilts toward osteoclastic activity.

- Of course, excessive load should not be imposed by the implant; too much force can damage the cells rather than enhance their activities.
- Fixation is accomplished by compressive or tensile force, the reduction (i.e., the placement of the broken bone ends near their former positions) should be anatomical, and the bone ends should be firmly fixed so that the healing processes cannot be disturbed by unnecessary micro- and macromovement

Wires,Pins

- Historically speaking, until Dr. J. Lister's aseptic surgical technique was developed in the 1860s, various metal devices such as wires and pins constructed of iron, gold, silver, platinum, etc., were not successful largely due to infection after implantation
- The simplest but most versatile implants are the various metal wires (called Kirschner wires when the diameter is less than 3/32 inch (2.38 mm) and Steinmann pins for those of larger diameter), which can be used to hold fragments of bones together.
- Wires can be monofilament or multifilament.
- Wires are used to reattach the greater trochanter in hip joint replacements or for long oblique or spiral fracture of long bones.
- The common problems of fatigue combined with corrosion of metals may weaken the wires in vivo. The added necessity of twisting and knotting the wires for fastening aggravates the problem since strength can be reduced by 25% or more due to the stress concentration effect. The deformed region of the wire will be more prone to corrosion than the undeformed region due to the higher strain energy.



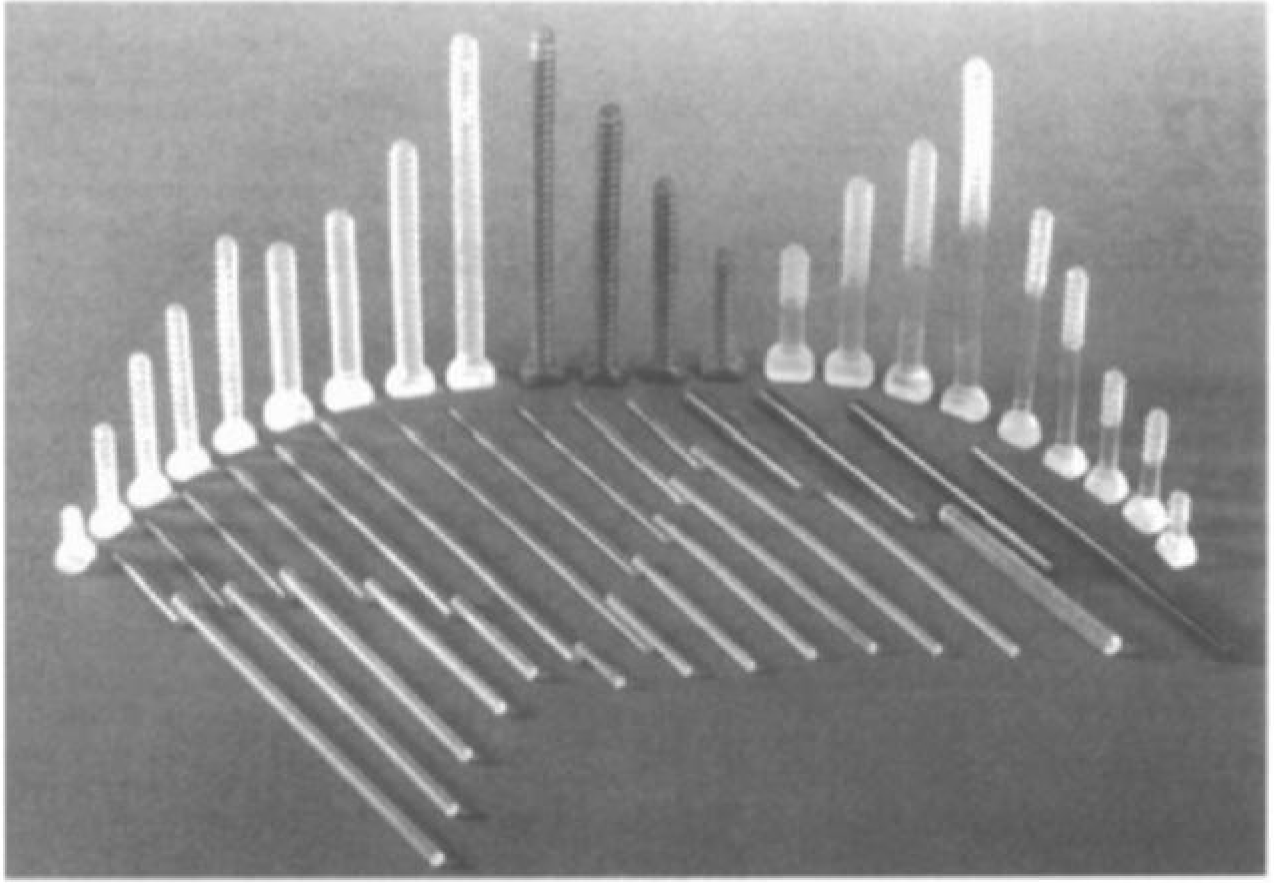
Proposed model for the feedback mechanism of the bone remodeling process due to mechanical energy input. Reprinted with permission from Kummer (1976). Copyright © 1976, Springer-Verlag.

Pins

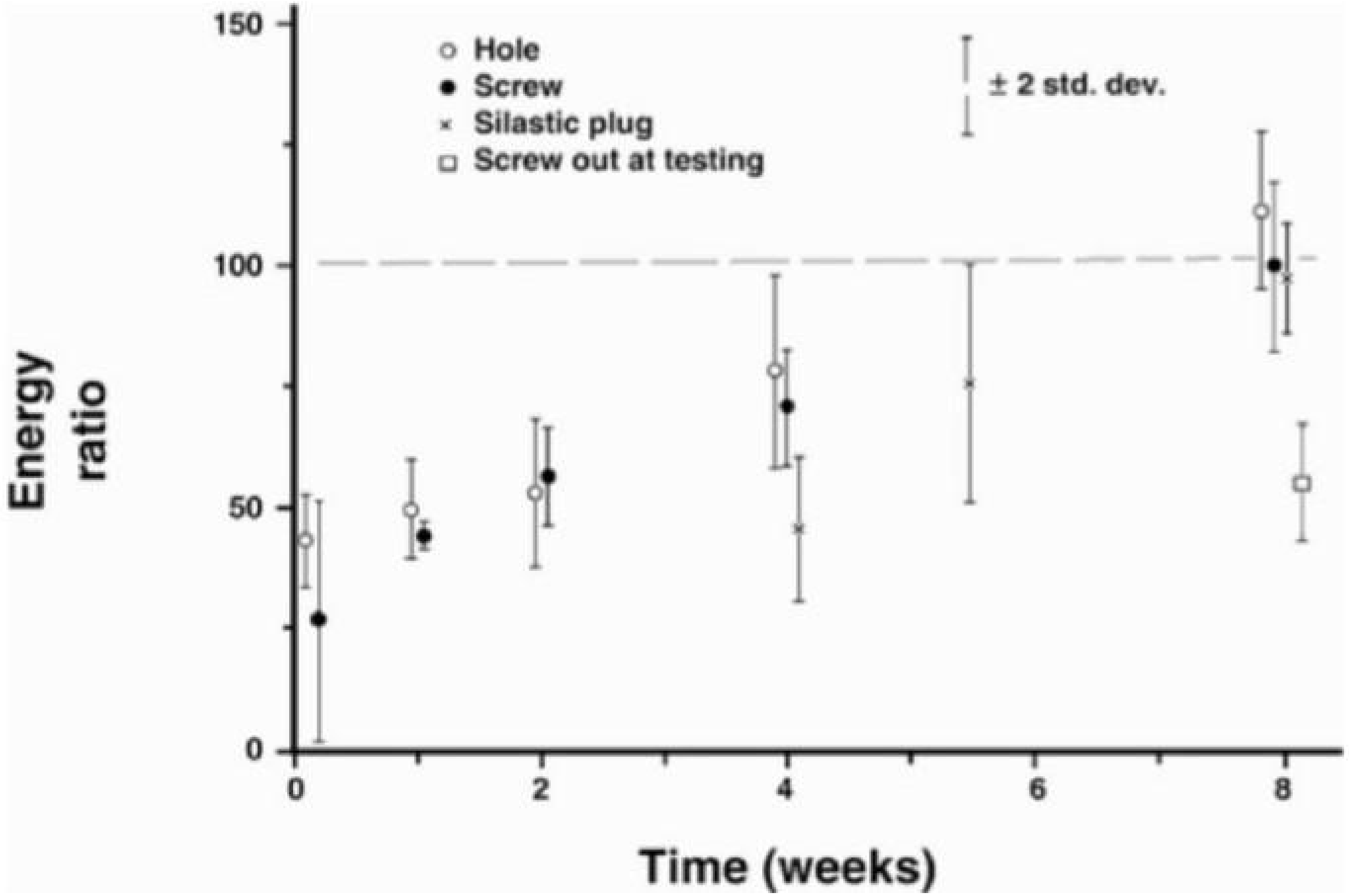
- The Steinmann pin is also a versatile implant often used for internal fixation in cases when it is difficult to use a plate or when adequate stability cannot be obtained by other means.
- The tip of the pin is designed to penetrate bone easily when the pin end is screwed into the bone. The fluting of the pin end differs from that of screws in that the flute angles of the pin are opposite to those of the screws.
- The reason for this is, in contrast to a screw or a drill, there is a lack of space between the hole created and the pin.

Screws

- Screws are some of the most widely used devices for fixation of bone fragments to each other or in conjunction with fracture plates
- Two types of screws: one is self-tapping and the other non-self-tapping (Figure 13-8). As the name indicates, a self-tapping screw cuts its own threads as it is screwed in. The extra step of tapping (i.e., cutting threads in the bone) required of the non-self-tapping screws make them less favorable, although the holding power (or pullout strength) of the two types of screws is about the same.
- The variations in thread design do not influence holding power.



Absorbable polymers are used to make pins, screws, and rods for orthopedic applications.



Hole
Screw
Silastic plug
Screw out at testing
± 2 std. dev.
Energy ratio
Time (weeks)
150
100
50
0
0
2
4
6
8

FRACTURE PLATES

- There are many different types and sizes of fracture plates (mainly metallic)
- Since the forces generated by the muscles in the limbs are very large, which generate large bending moments, the plates must be strong
- adequate fixation of the plate to the bone with the screws is important
- overtightening may result in necrosed bone as well as deformed screws which may fail later due to the corrosion process at the deformed region
- One major drawback of healing by rigid plate fixation is weakening of the underlying bone such that refracture may occur following removal of the plate. This is largely due the stress-shield effect upon the bone underneath the rigid plate.
- The stiff plate can carry so much of the load that the bone is understressed, so that it is reabsorbed by the body according to Wolff's law. In addition, the tightening of the screws that hold the bone plate creates a concentrated stress upon the bone; this can have a deleterious effect if the screws are in cancellous bone.
- In order to alleviate osteopenia due to stress shielding, resorbable bone plates made of poly-l-glycolic acid (PLGA) have been tried experimentally. Such plates are available for small bones

Limitations and how to overcome

- If conventional metal screws are used instead, they are usually removed surgically after healing, as is the case with conventional metal bone plates.
- Moreover, manipulation of the resorbable plate in situ by the surgeon is difficult, if not impossible; additional equipment such as an oven may be required to heat and shape these thermoplastic materials to fit the bone.
- It would be desirable to reduce the problems of refracturing of bone due to screw holes and weakened osteoporotic bones under the fixation plate
- These problems may be reduced if one were to design the plate in such a way where a polymer insert (UHMWPE) can be made to creep (slowly deform with time), transferring load more toward to bone, which will result in a reduced osteoporotic effect

•Kirschner wires or K-wires or pins are sterilized, sharpened, smooth stainless steel pins. Introduced in 1909 by Martin Kirschner, the wires are now widely used in orthopedics and other types of medical and veterinary surgery.

•They come in different sizes and are used to hold bone fragments together (pin fixation) or to provide an anchor for skeletal traction.

•The pins are often driven into the bone through the skin (percutaneous pin fixation) using a power or hand drill.

Stainless Steel 316LVM Wire.

•For implantable medical devices
•For fabricating components
•Small diameter wire
•Chemical composition : Cr, Ni, Mo, Mn.
•Suitable close-tolerance

Stainless Steel 304V Wire.

•Chemical composition: Chromium, Nickel, Carbon, Manganese, Molybdenum, Silicon, Phosphorus, Copper, Cobalt, Nitrogen.
•Least expensive medical materials
•Excellenth strength
•Easy to weld

Nitinol Wire.

•Pure Titanium
•Extreme tolerance
•Does not induce toxic or inflammatory reactions. Biocompatibility

Pins

- Straight wires are called Steinmann pins
- They are widely used primarily to hold fragments of bones together provisionally or permanently and to guide large screws during insertion. To facilitate implantation, the pins have different tip designs which have been optimized for different types of bone.
- Most pins are made of 316L stainless steel; however, recently, biodegradable pins made of polylactic or polyglycolic acid have been employed for the treatment of minimally loaded fractures.

Types of Steinmann pins

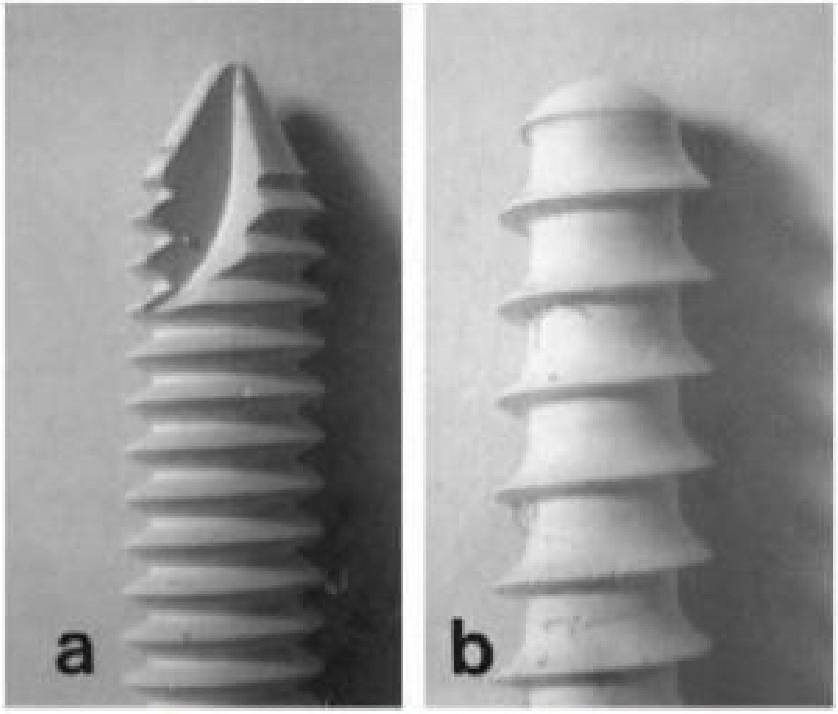
Screws

Screws are the most widely used devices for fixation of bone fragments.

There are two types of bone screws:
(1) cortical bone screws, which have small threads
(2) cancellous screws, which have large threads to get more thread-to-bone contact. They may have either V or buttress threads.

The cortical screws are subclassified further according to their ability to penetrate: self-tapping and nonself- tapping .
The self-tapping screws have cutting flutes which thread the pilot drill-hole during insertion. In contrast, the non-self-tapping screws require a tapped pilot drill-hole for insertion.

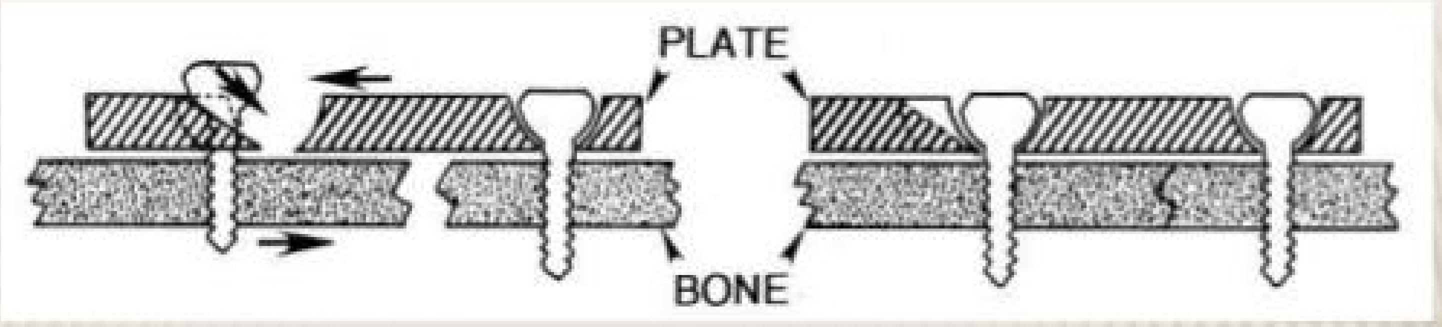
The holding power of screws can be affected by the size of the pilot drill-hole, the depth of screw engagement, the outside diameter of the screw, and quality of the bone. Therefore, the selection of the screw type should be based on the assessment of the quality of the bone at the time of insertion. Under identical conditions, self-tapping screws provide a slightly greater holding power than non-self-tapping screws



Bone screws: (a) a self-tapping V-threaded (has a cutting flute), and (b) a non-self-tapping,

Biomaterials used in Internal Fixation

Materials	Properties	Application
Stainless Steel	Low cost, easy fabrication	Surgical wire (annealed)
		Pin, plate, screw
		IM nail
Ti alloy	High cost	Surgical wire
	Low density and modulus	Plate, screws, IM nails
	Excellent bony contact	
Co–Cr alloys (wrought)	High cost	Surgical Wire
	High density and modulus	IM Nails
	Difficult fabrication	
Poly lactic acid	Resorbable	Pin, screw
Poly glycolic acid	Weak strength	
Nylon	Non-resorbable plastic	Cerclage band



Principle of a dynamic compression plate for fracture fixation. During tightening a screw, the screw head slides down on a ramp in a plate screw hole which results in pushing the plate away from a fracture end and compressing the bone fragments together.

The interaction between bone and plate:

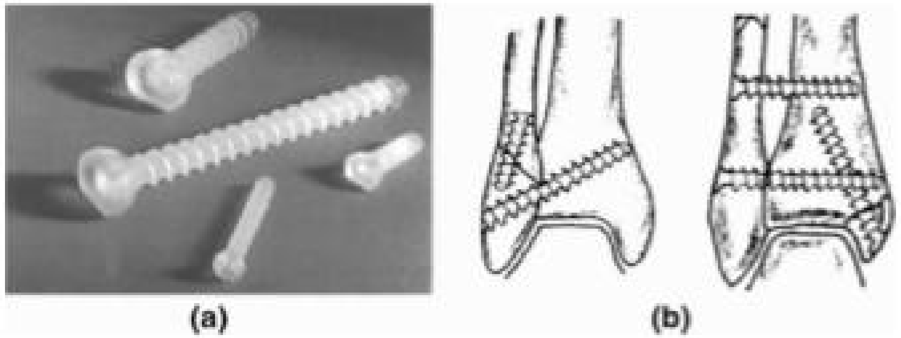
Compression

Tension

Types of Plates

Stiff Plates
Long bones
Stainless steel alloys

Flexible plates
Cancellous bones
Titanium alloys and PLGA



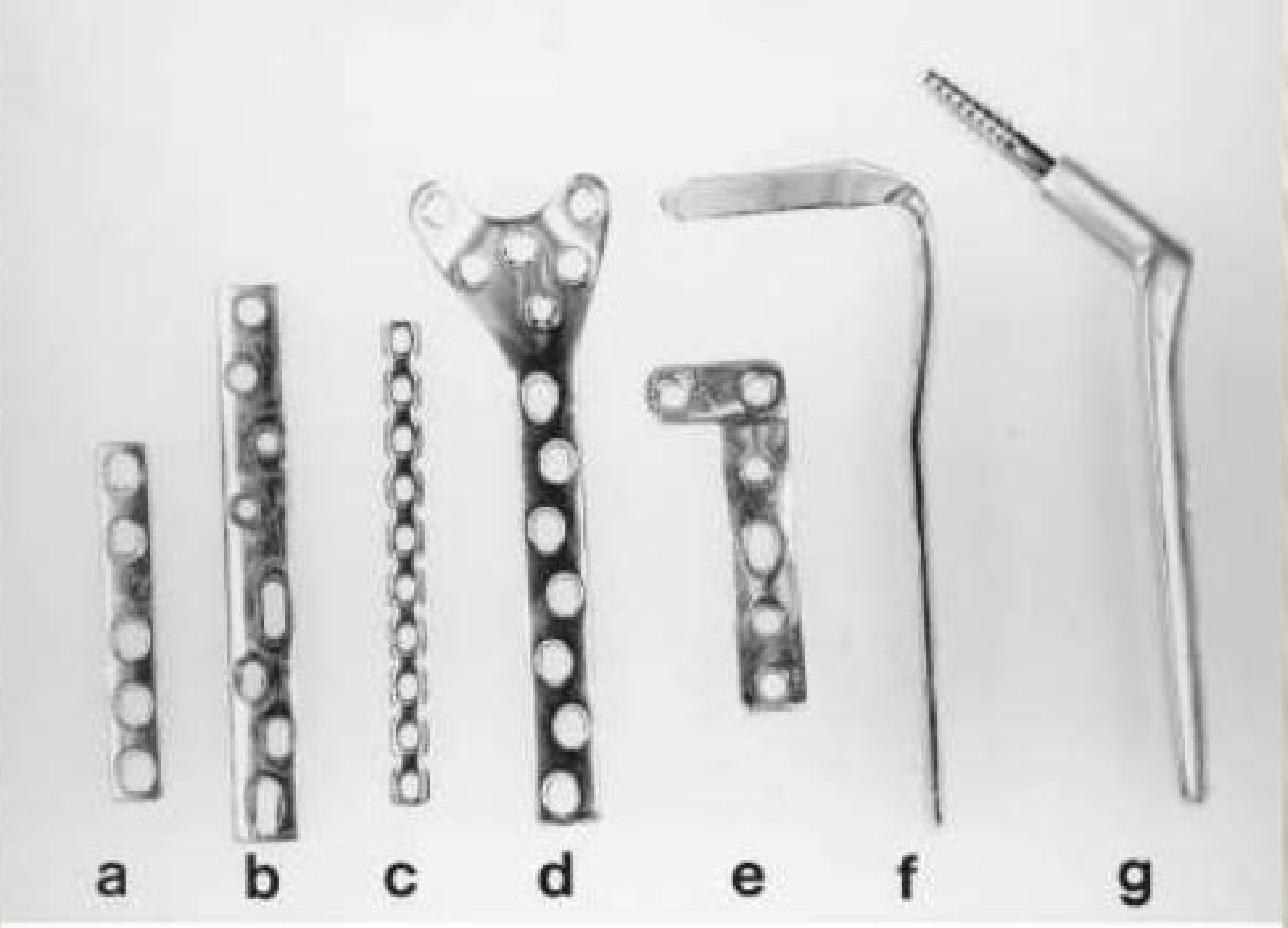
Biodegradable PGA bone screws (**a**) and depiction of the application in cancellous bone fractures (**b**). Reprinted with permission from van der Elst et al. (2000). Copyright © 2000, Marcel Dekker.

Salient features for long bone repair

- The kinematics and dynamic load transfer characteristics of the joint dependent material properties, shape and methods used for fixation- overloading the implant –bone interface or shielding it from load transfer may result in bone resorption and subsequent loosening of the implant
- The articulating surfaces of the joint should function with minimum friction and produce the least amount of wear products
- The implant should be securely fixed to the body as early as possible
- Loss of tissue, especially of bone, makes reimplantation difficult and often shortens the life span of the second joint replacement

Types of plates

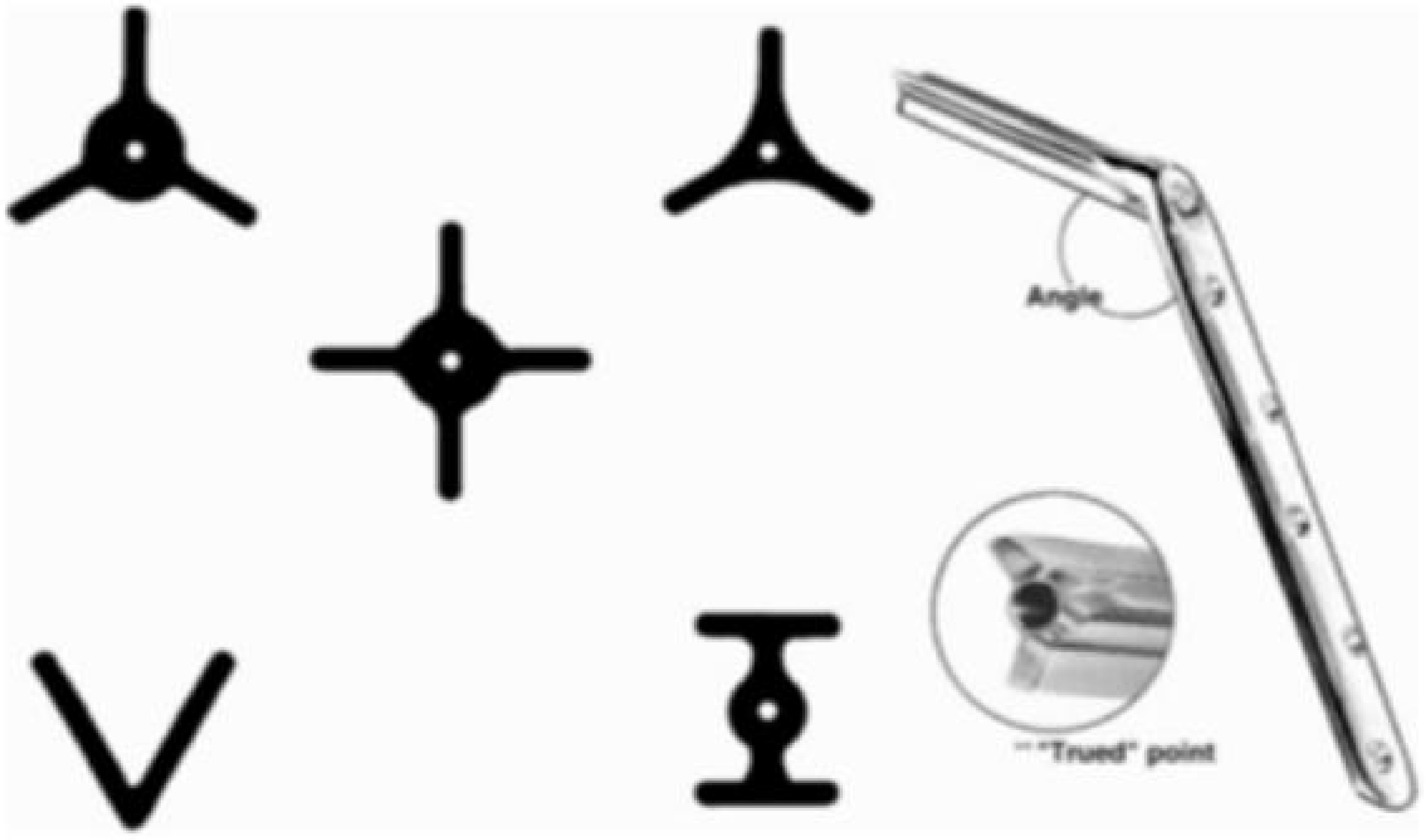
- Dynamic Compression Plate(DCP)-Compression between the fracture fragments can be achieved by this type of plate. It has elliptical screw holes with its long axis oriented parallel to that of the plate. The screw hole has a sliding ramp to the long axis of the plate.
- Buttress Plate- In the vicinity of the joints, where the diameter of long bones is wider, the cortex thinner, and cancellous bone abundant, plates are often used as a buttress or retaining wall. A buttress palte applies force to the bone perpendicular to the surface of the plate and prevents shearing or sliding at the fracture site.
- Buttress plates are fixed by a larger lag screw than the conventional screws used for other plates.



Bone Plates: (a) dynamic compression plate, (b) hybrid compression plate (lower part has dynamic compression screw holes), (c) reconstruction bone plate (easy contouring), (d) buttress bone plate, (e) L shaped buttress plate, (f) nail plate (for condylar fracture), and (g) dynamic compression hip screw.

INTRAMEDULLARY DEVICES

- Intramedullary devices are used to fix fractures of long bones. The devices are snugly inserted into the medullary cavity . This type of implant should have some spring in it to exert some elastic force inside the bone cavity to prevent rotation of the device and to fix the fracture firmly.
- Compared to plate fixation, the intramedullary device does not involve placement of multiple screws.
- Its torsional resistance is much less than that of the plate. It is also believed that the intramedullary device destroys the intramedullary blood supply but does not disturb the periosteal blood supply, in contrast to the case of plate fixation.
- Another advantage of the intramedullary device is that it does not require opening of a large area to operate, and the device can be nailed through a small incision.
- Various designs are possible depending on the radius required, cross-sectional shapes and fixation unit
- The closed (solid) designs of the four-flanged nail (Schneider) and the diamond nail showed higher resistance to torsion than the open cloverleaf nail.



. Cross-section of various hip nails and a typical implant and its insertion tip.

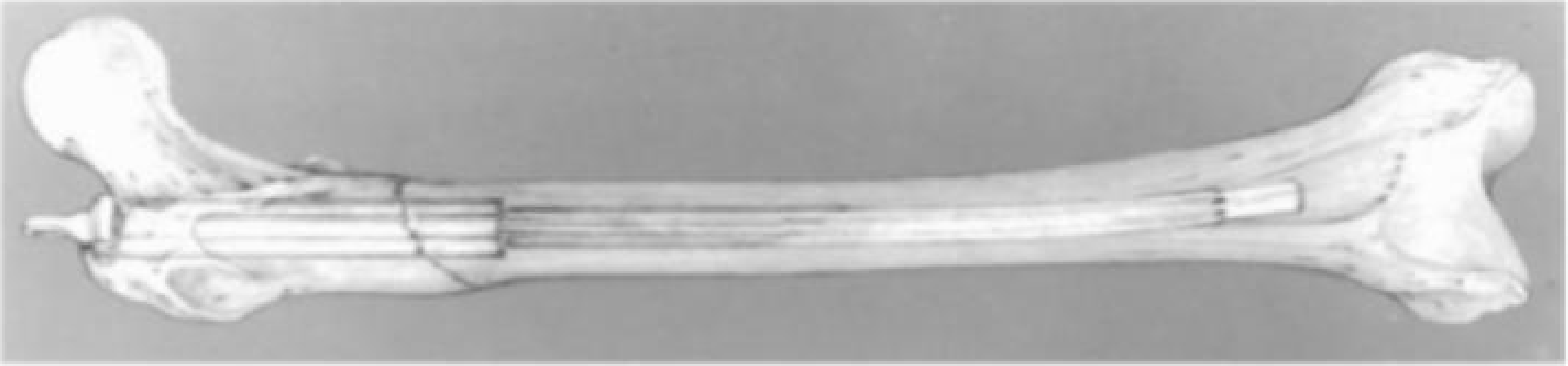


Illustration of an intramedullary device used in the femur.

BIOMATERIALS FOR TOTAL JOINT REPLACEMENTS

Materials	Applications	Properties
Co–Cr alloy (casted or wrought)	Stem, head (ball) Cup, porous coating Metal backing	Heavy, hard, stiff High wear resistance
Ti alloy	Stem, porous coating Metal backing	Low stiffness Low wear resistance
Pure titanium	Porous coating	Excellent osseousintegration
Tantalum	Porous structure	Excellent osseousintegration Good mechanical strength
Alumina	Ball, cup	Hard, brittle High wear resistance
Zirconia	Ball	Heavy and high toughness High wear resistance
UHMWPE	Cup	Low friction, wear debris Low creep resistance
PMMA	Bone cement fixation	Brittle, weak in tension Low fatigue strength

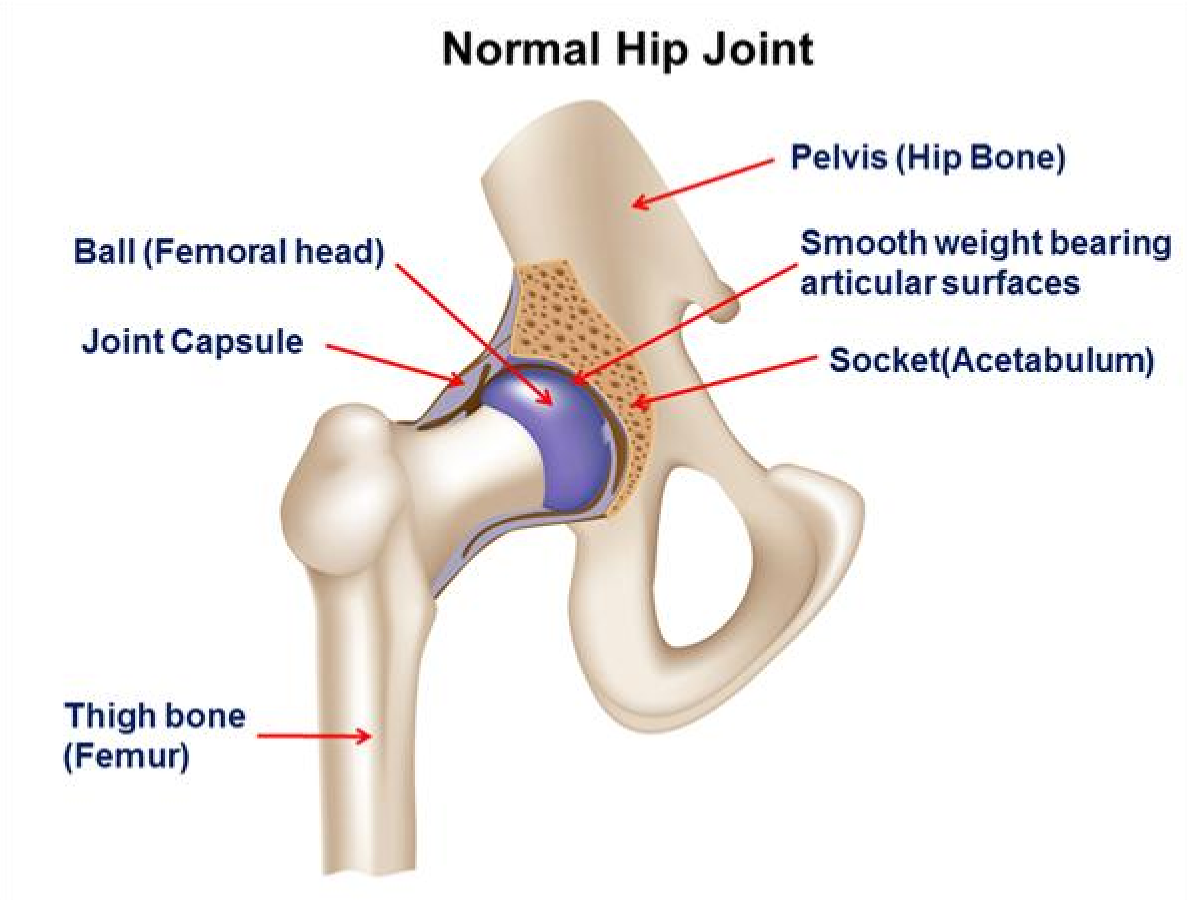
TYPES OF TOTAL JOINT REPLACEMENTS

Joint	Types
Hip	Ball and socket
Knee	Hinged, semiconstrained, surface replacement
	Unicompartment or bicompartment
Shoulder	Ball and socket
Ankle	Surface replacement
Elbow	Hinged, semiconstrained, surface replacement
Wrist	Ball and socket, space filler
Finger	Hinged, space filler

Hip Replacements

- A damaged hip joint is surgically replaced with an artificial implant.
- Patients require differing degrees of replacements, such as total or partial implants, and new hips are made from plastic, ceramic and metal materials.

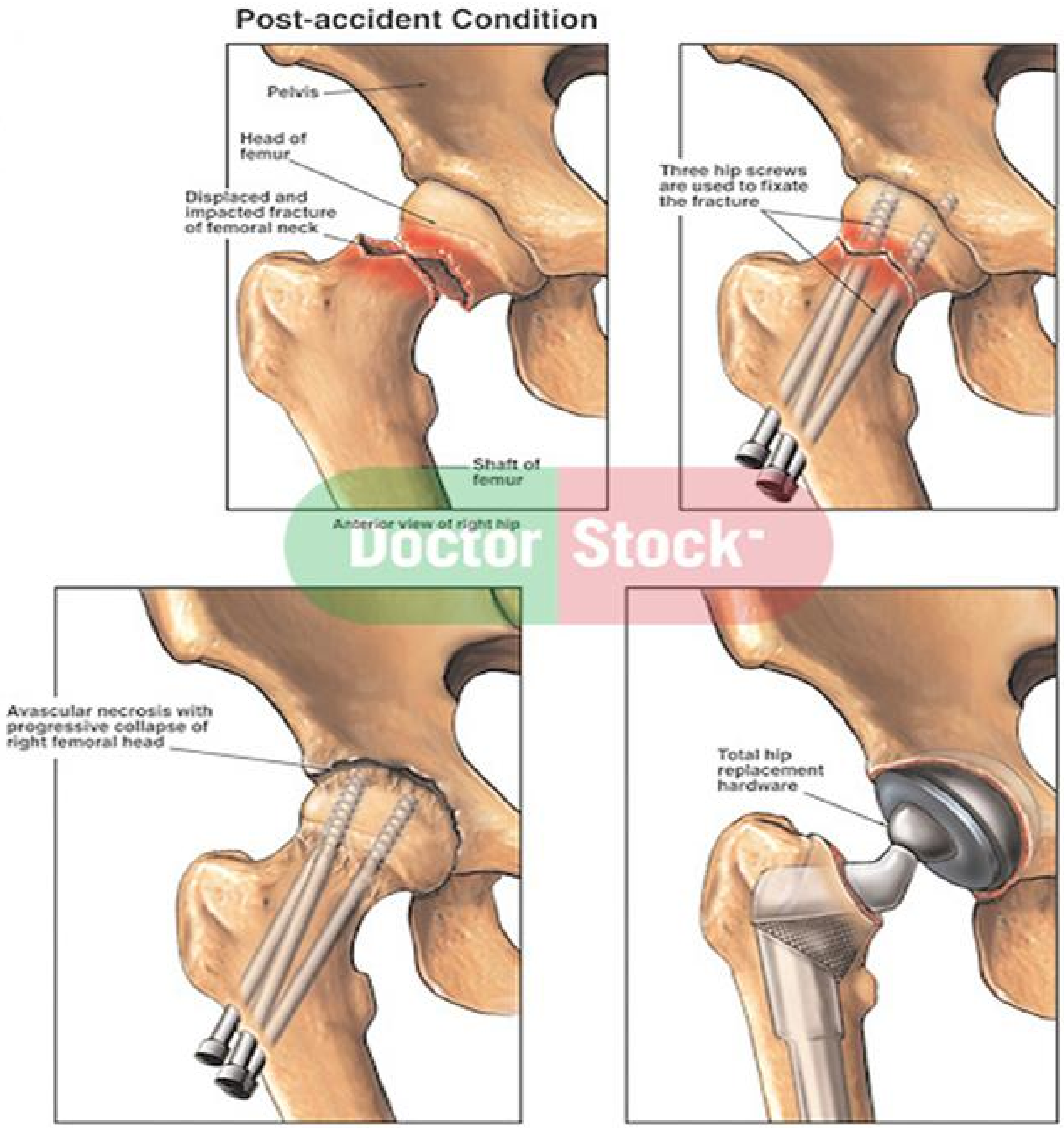
1. Total Hip Replacement (THR)
2. Partial Hip Replacement
3. Hip Resurfacing

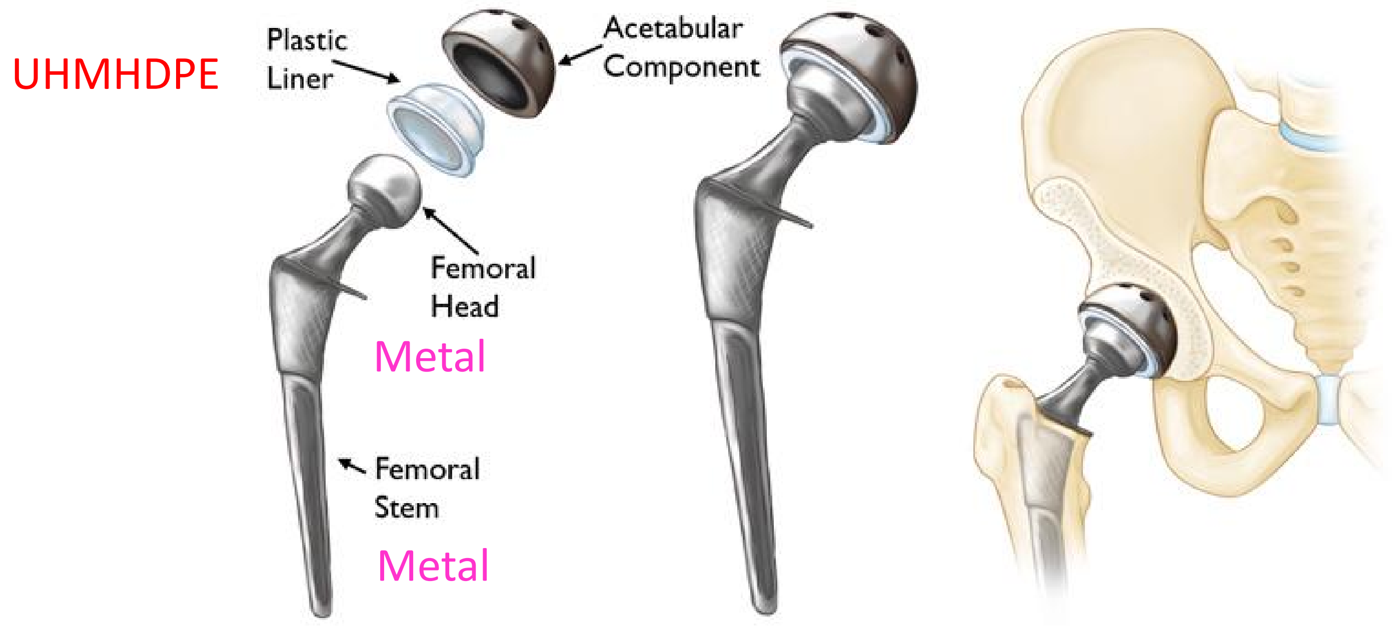


When do we require hip joint replacement?

Osteoarthritis in the hip is a condition where the surface(cartilage) of the joint of the hip gradually wear away resulting in inflammation. This may happen because of a specific previous injury and due to over repetitive forces on the hip, which goes beyond the tolerance limit of the hip after a certain period of time.

Traumatic Hip Fracture (Broken Hip) with Surgical Fixation and Total Joint Replacement (Arthroplasty).





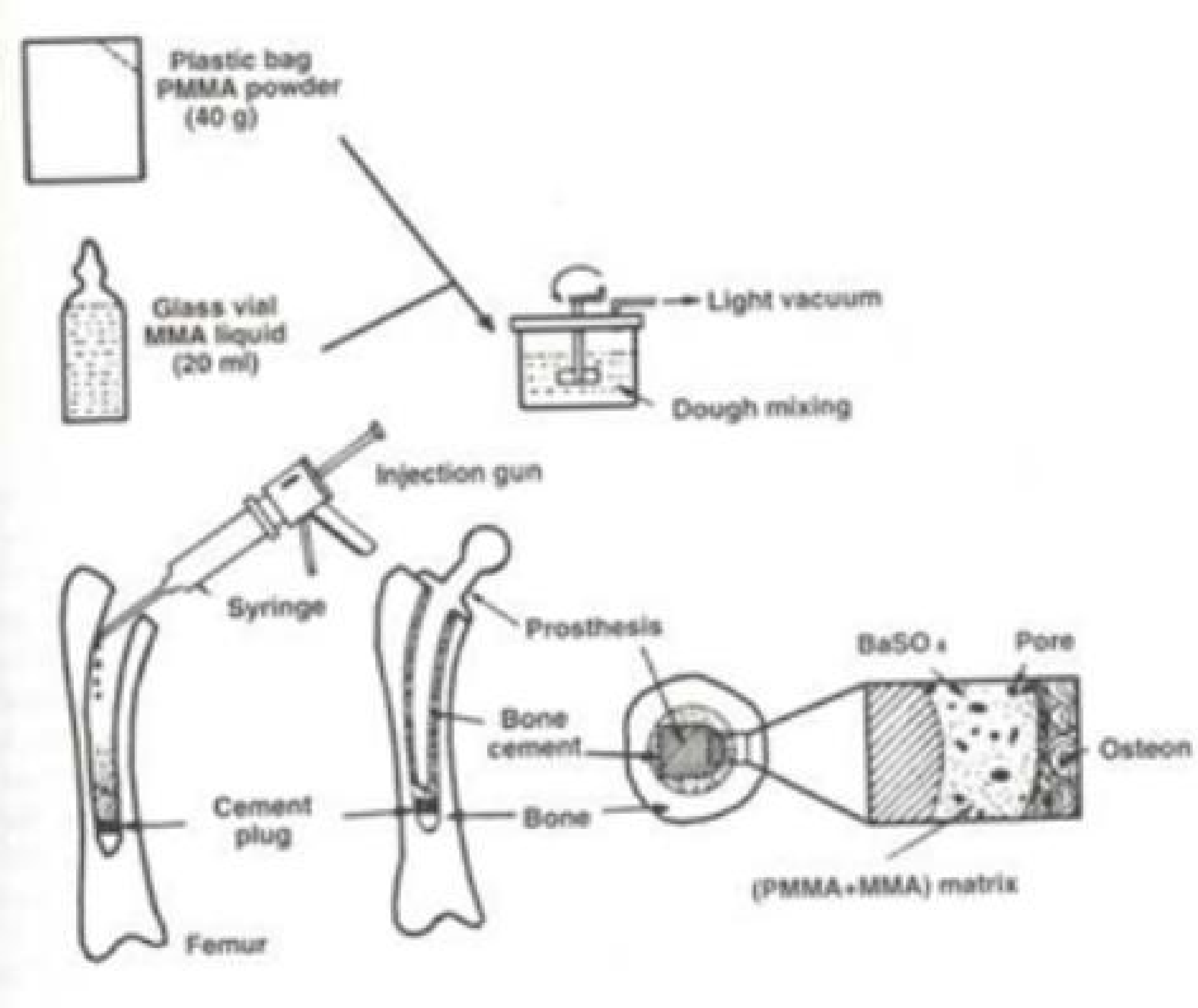
- Marius Smith-Petersen, an American surgeon made the first arthroplasty mold in 1925, and went on to create the first total hip replacement (THR), made with stainless steel.
- In 2015, U.S. surgeons performed an estimated 378,000 total hip replacements
- The average cost of a total hip replacement is about $30,000
- The surgery takes about 1-2 hours, plus another 1-2 hours of prep time before hand. The patient's size and overall health may also influence these estimates. After the surgery patients will stay a few days in the hospital and have to take blood thinners to prevent blood clots.

Dr. D. Charnley used bone cement for fixation.

Salient Features of Total Hip replacement

- The diseased femoral head is cut off and the medullary canal of the femur is drilled and reamed to prepare it for the stem of the prosthesis.
- The cartilage of the acetabulum is also reamed.
- PMMA bone cement is prepared from polymer powder and monomer liquid till the correct dough consistency is reached-it is packed into the medullary canal of the femur and the femoral stem is inserted.
- Replace the head of the femur with a ball and replace the socket with an artificial cup.

Procedure of hip joint replacement



Biomaterials-an Introduction by J.B. PARK

Salient features of hip replacement

- Special bone cement usually holds hip implants in place
- Cementless fixation technique-specially textured surface that encourages the bone to grow onto the implant and secure it in place.
- A hybrid total hip replacement uses a combination of both, implanting the cup without cement and setting the stem in place with cement.
- Traditional Charnley type hip replacement used UHMWHDPE acetabular cup and metallic (stainless steel 316L, Co-Cr and Ti based alloys) femoral head and stem
- In original Charnley prosthesis PTFE was used in place of PE

Partial hip replacement & resurfacing

- Either acetabulum or femoral head can be replaced or hip fracture in the neck of femor can be rectified by the same procedure as earlier.

Hip resurfacing is done to avoid bone loss due to errosion.

It replaces the socket with an artificial cup and resurfaces the head of femur by cementing process.

- This component has a short stem inserted into the neck of the femur.
- Hip resurfacing often improves symptoms of arthritis.

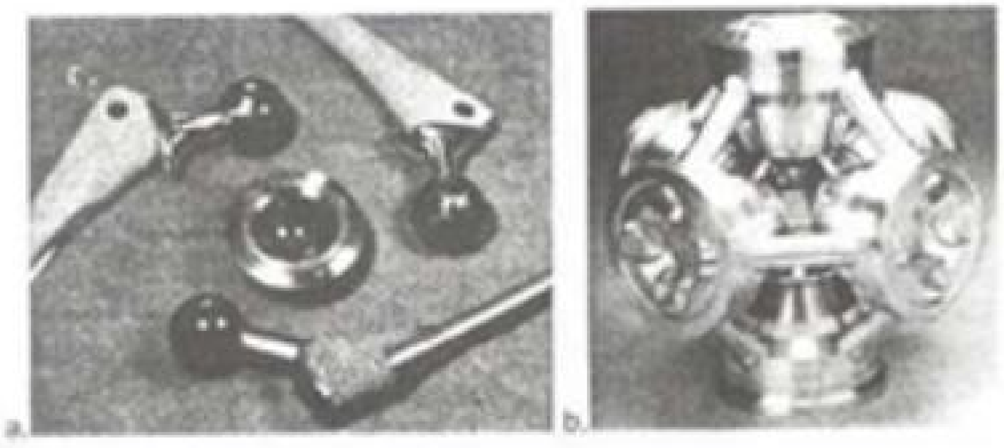
Hip Implant Devices

- Metal –on –metal
- Metal on Plastic
- Ceramics-on -metal
- Ceramics on Plastic
- Ceramics on Ceramics

Charnley Hip Prosthesis-
Polymeric cup and femoral stem with small diameter head claimed to be low friction with less contact surface

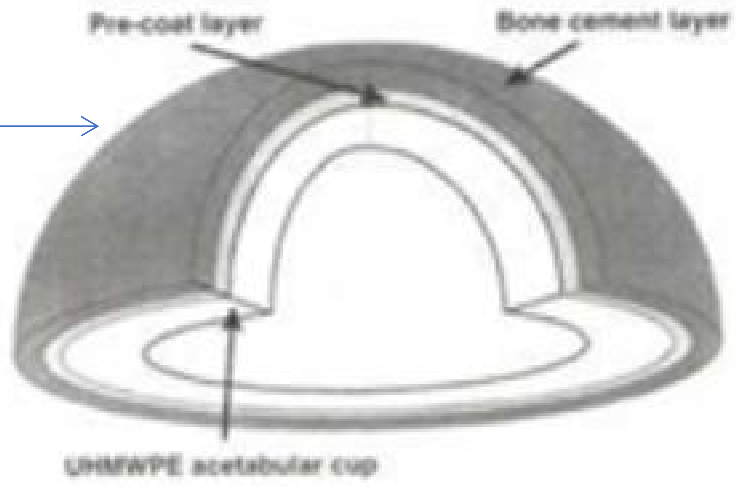
Difficulties

- Fixation of implants-due to the fact that the implant has an interface with the cancellous bone which is much weaker than compact bone.

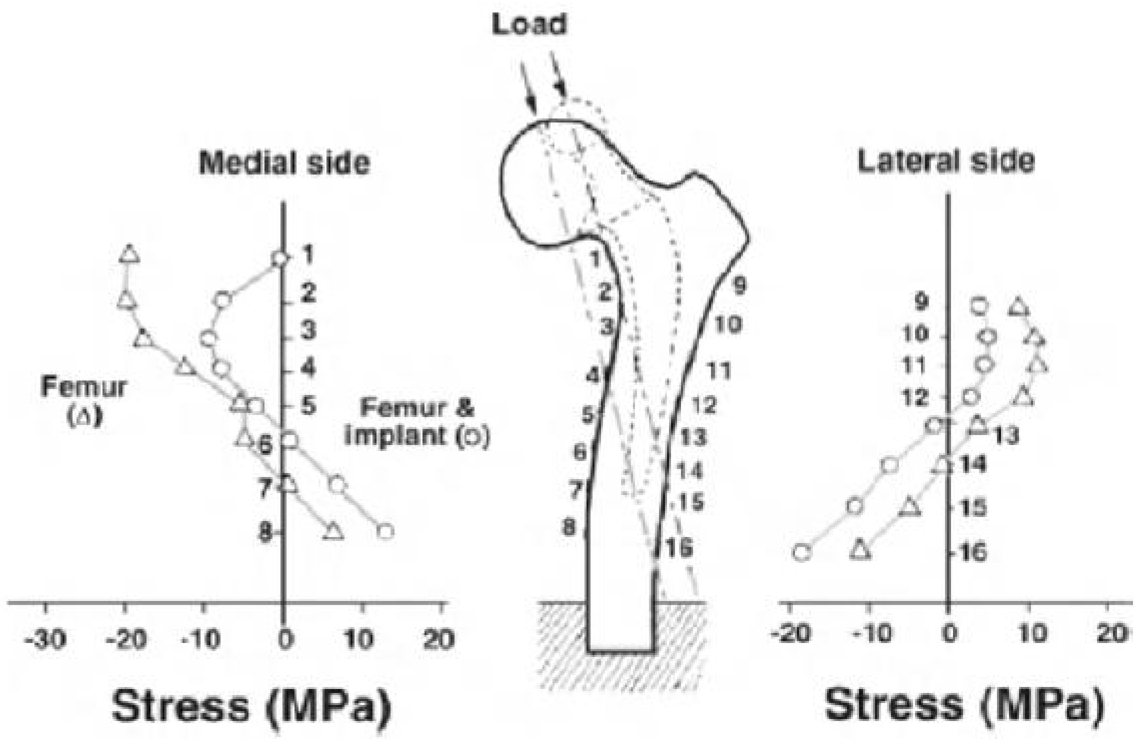


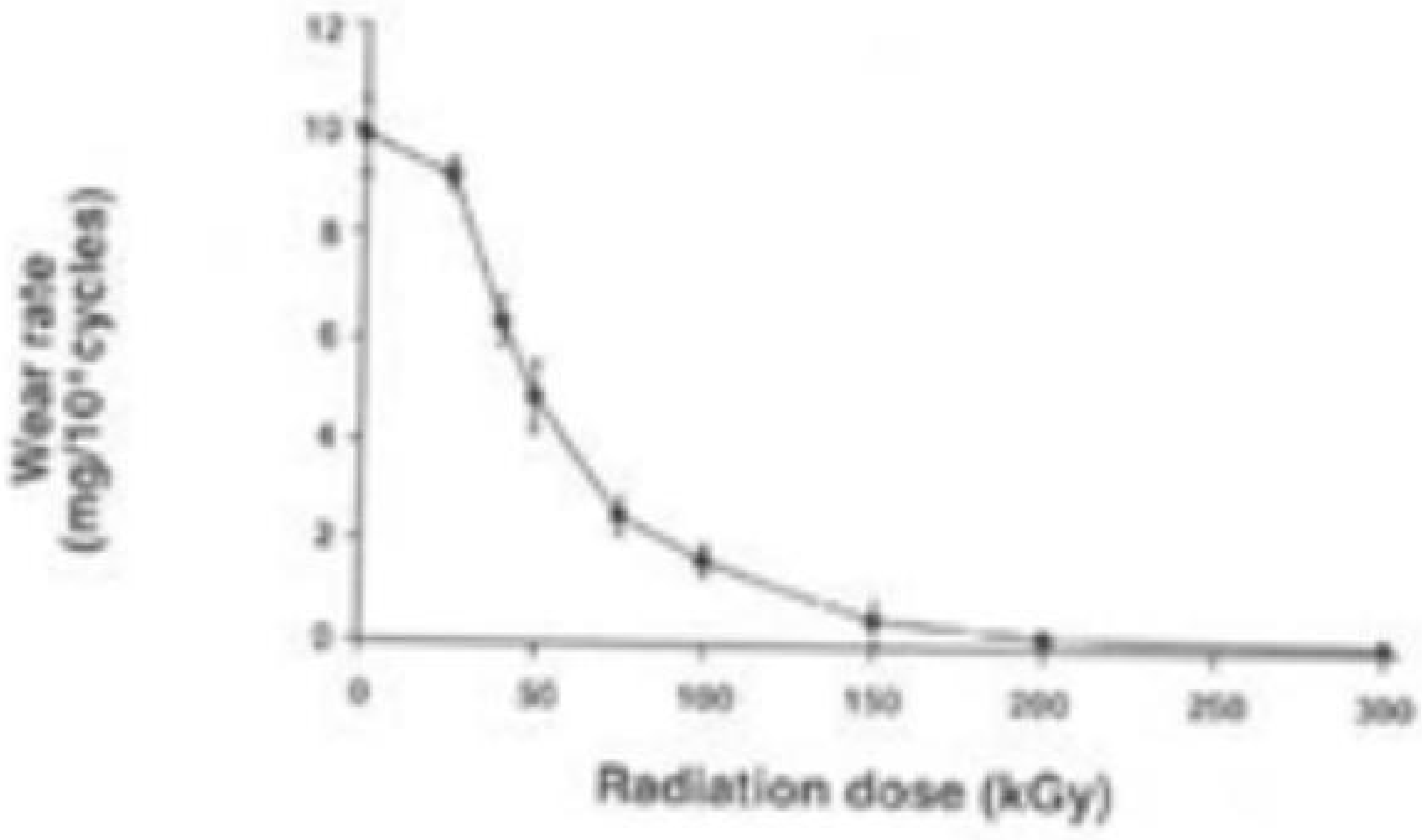
Coating surfaces of head and cup with compact diamond

Pre-coating all-poly acetabular cup outer surface with bone cement layer combined with X-linked UHMWPE



Stresses on the surface of the femoral stem by a load of 4000N.



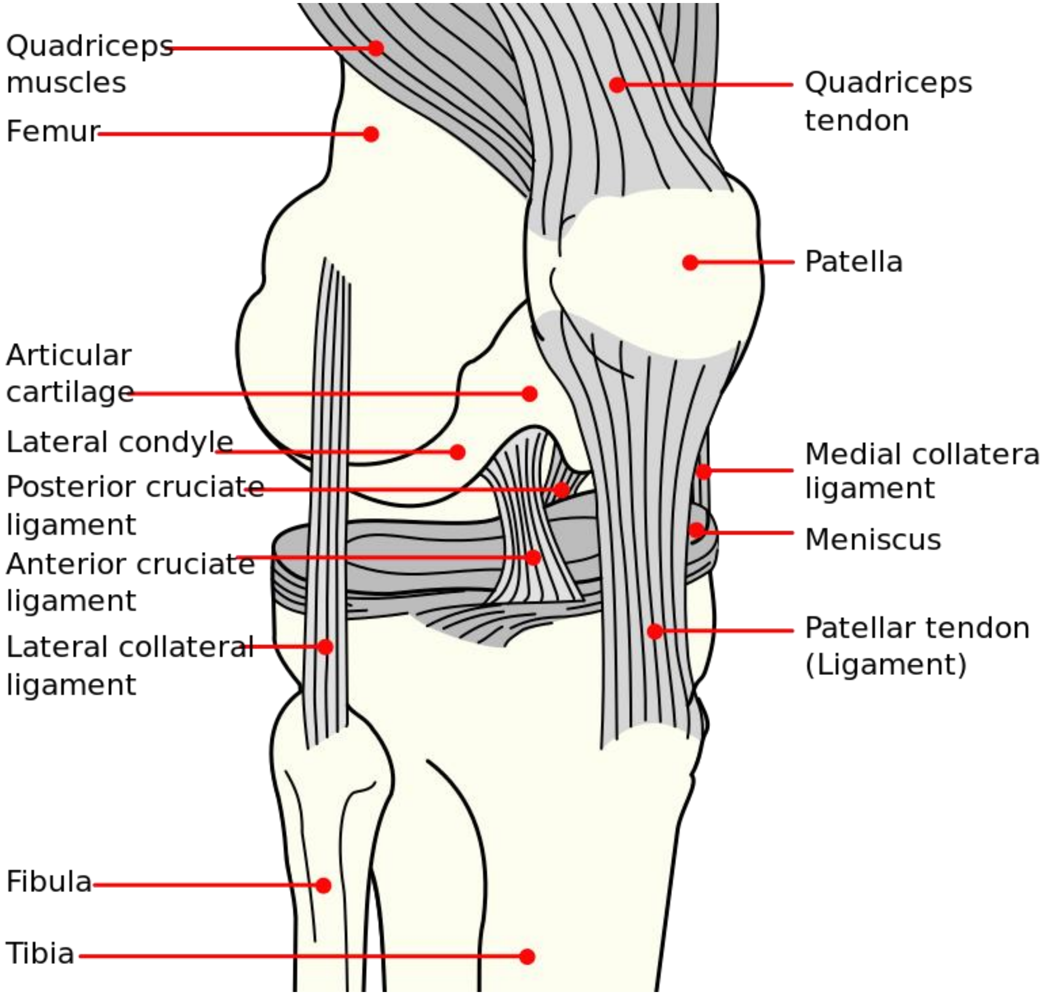


Wear rate Vs. Degree of X-links(radiation dose)

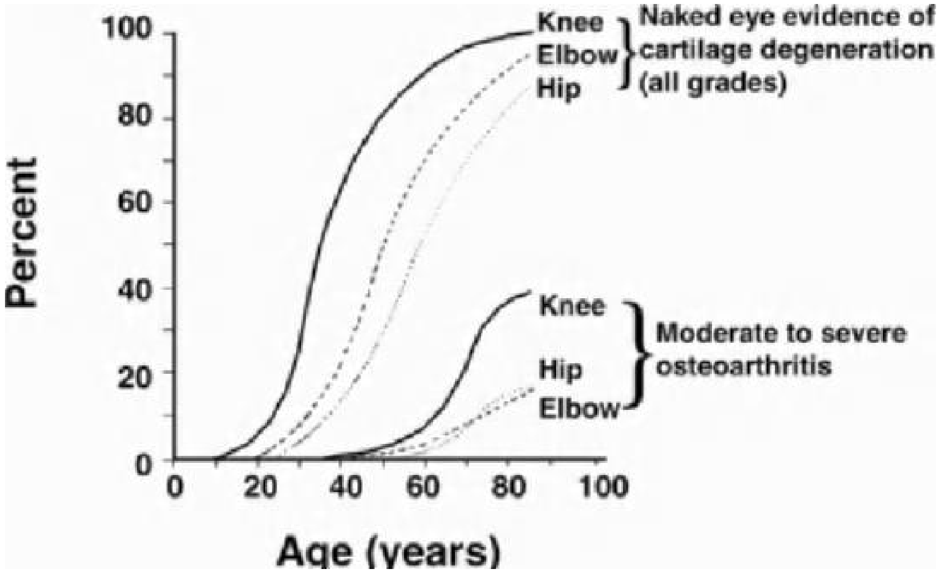
knee joint anatomy

The knee can be thought of as having 3 compartments - the medial, the lateral, and the patella femoral. In addition, there are 2 special cartilages within the knee joint called the lateral and medial meniscus, which act as shock absorbers within the knee joint. There are also 2 ligaments within the knee, called the anterior cruciate ligament and the posterior cruciate ligament, which contribute to knee stability.

The ends of the bone are covered with a smooth, glistening layer called articular cartilage. The articular cartilage is what allows the bones to glide smoothly with less resistance than ice sliding on ice. The articular cartilage can be seen on x-ray as the space in between the bones.



Incidence of Joint Degeneration

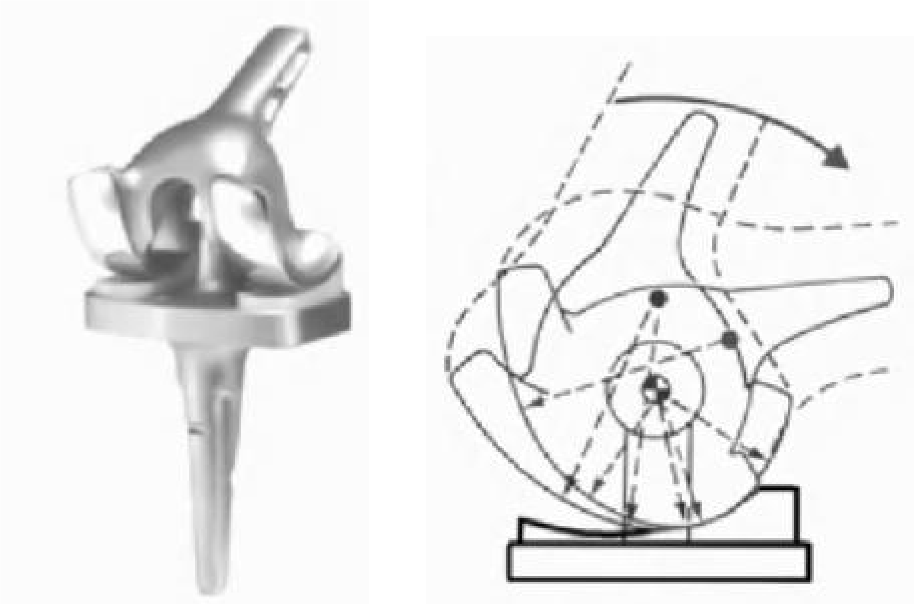


Development and acceptance of knee joint prostheses –slower than that of hip joint

Reason:

- Knee 's complicated geometry and biomechanics of movement-it rolls and glides simultaneously
- Lesser stability

a)Freeman-Swanson



b)Spherocentric

c) Walldius

e) Bechtol

Types of artificial knee joints

Classification of replacements

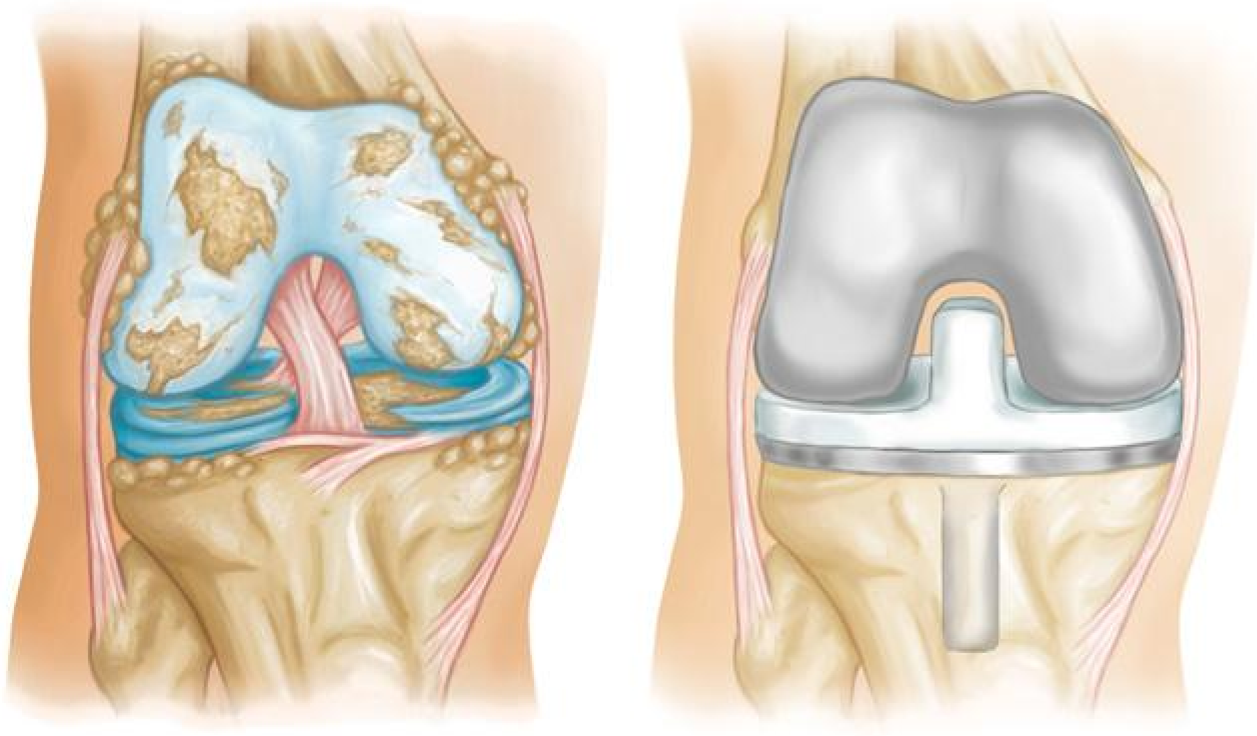
- Hinged
- Non-hinged

  -uni-compartmental

  -bi-compartmental

Partial Knee Replacement Implant

Total Knee Replacement Implant



Damaged knee

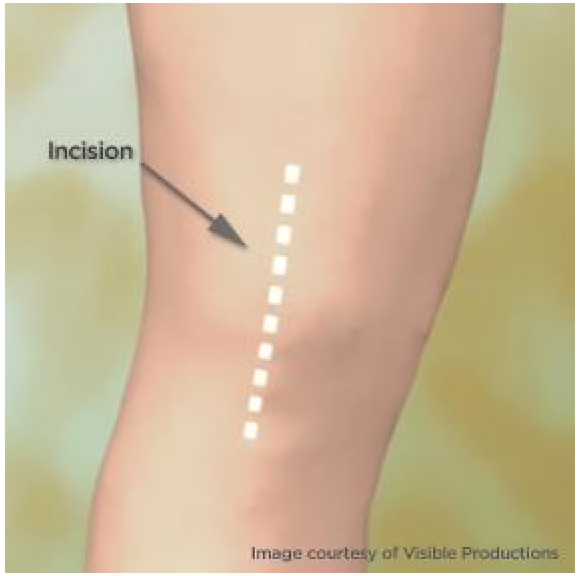
After replacement

- Damage from arthritis is the most common reason for knee joint replacement. This includes both osteoarthritis and rheumatoid arthritis.
- The prosthesis is made of metal alloys and polymers

Steps of Knee Replacement

- A total knee replacement (TKR) is a complex procedure that requires an orthopedic surgeon to make precise measurements and skillfully remove the diseased portions of your bone, in order to shape the remaining bone to accommodate the knee implant. During the procedure, the surgeon builds the artificial knee inside your leg, one component at a time, to create a highly realistic artificial joint.

The surgeon makes an incision across the front of your knee to gain access to the patella, more commonly referred to as the kneecap. In a traditional knee replacement, the incision is usually about 8 to 10 inches long. In minimally invasive knee surgery, the incision is usually about 4 to 6 inches long.



The first part of your knee that is exposed is your kneecap, called the *patella*. Once your knee is open, the surgeon rotates the patella outside the knee area. This allows the surgeon to view the area needed to perform the surgical procedure.

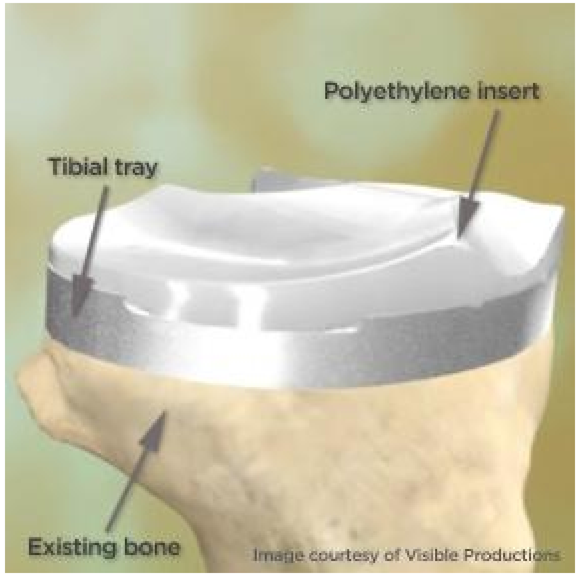
The first bone your surgeon will resurface is your femur, commonly known as the thighbone.

- Once the surgeon has opened up and exposed knee joint, he or she will carefully measure the bones and make precise cuts using special instruments.
- The damaged bone and cartilage from the end of the femur is cut away. The end of the femur is cut and resurfaced to fit the first part of the artificial knee, the femoral component.

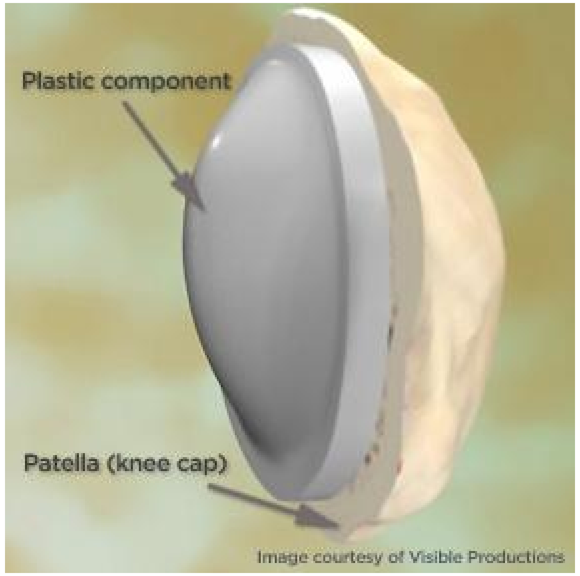
The surgeon attaches the metallic femoral component to the end of the femur and uses bone cement to seal it into place.

The surgeon then resurfaces the tibia, or shinbone. The surgeon removes damaged bone and cartilage from the top of the tibia and then shapes the bone to fit the metal and plastic tibial components.

The bottom portion of the implant, called the tibial tray, is fitted to the tibia and secured into place using bone cement. Once the tray is in place, the surgeon will snap in a polyethylene (medical-grade plastic) insert to sit between the tibial tray and the femoral component, and act as a kind of buffer. This insert will provide support for your body as you bend and flex your knee.



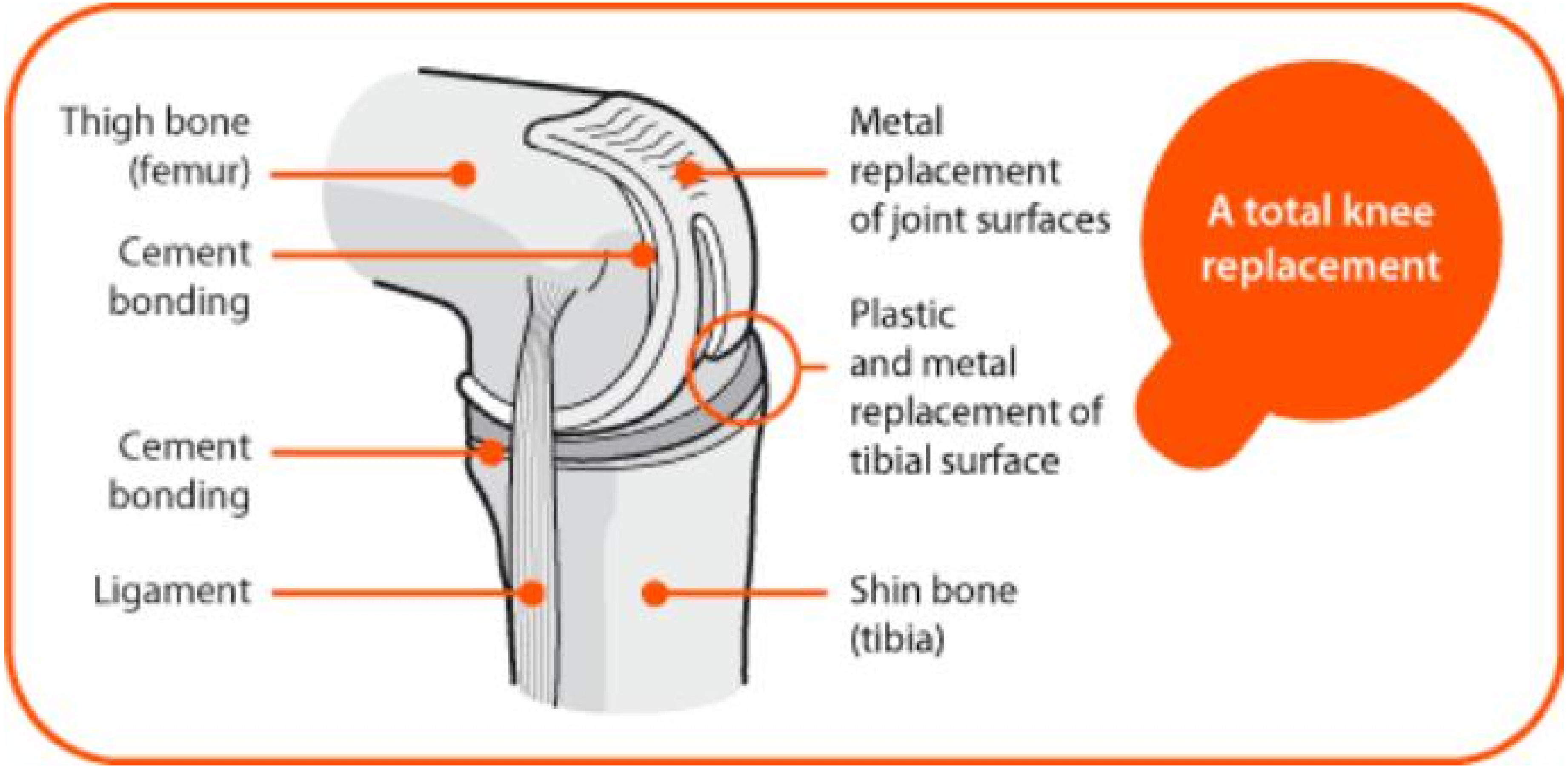
Before returning the patella to its normal position, the surgeon might need to flatten the patella and fit it with an additional plastic component in order to ensure a proper fit with the rest of your implant. The plastic piece, if needed, is cemented to underlying bone.

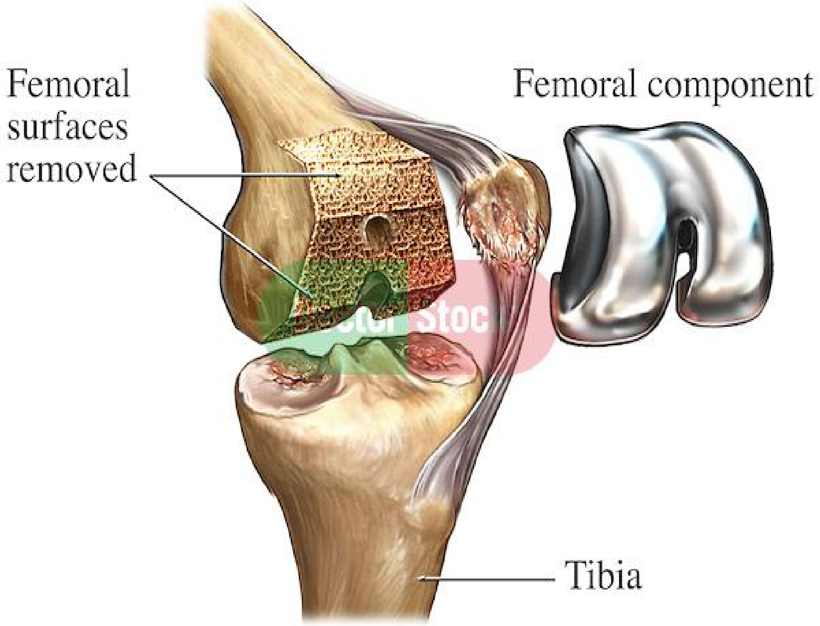


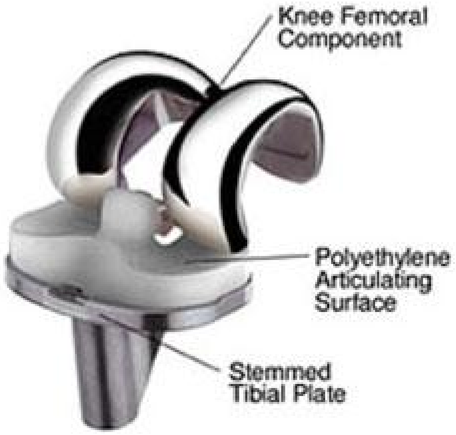
Your surgeon will bend and flex the knee to ensure that the implant is working correctly, and that alignment, sizing, and positioning is suitable.

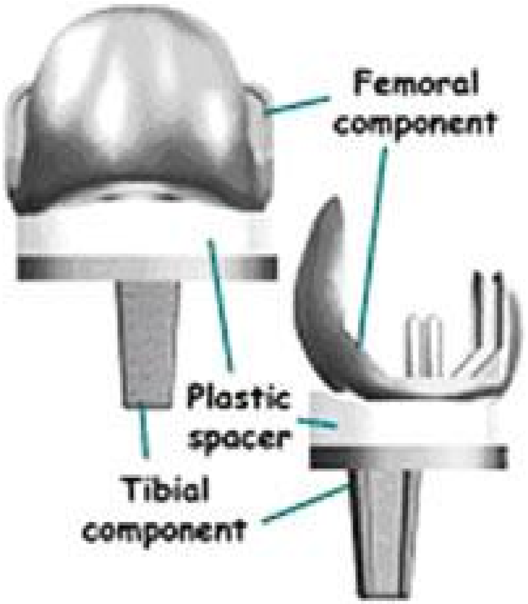
- close the incision with stitches or staples, and then bandage it and prep you for recovery.
- leg in a continuous passive motion (CPM) machine that will gently bend and flex your new knee for you while you are lying down.

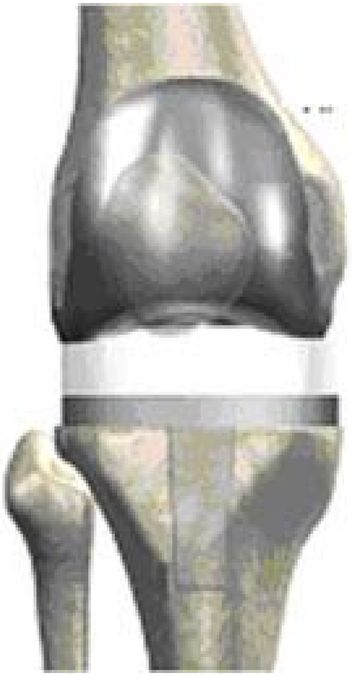
Total knee replacement



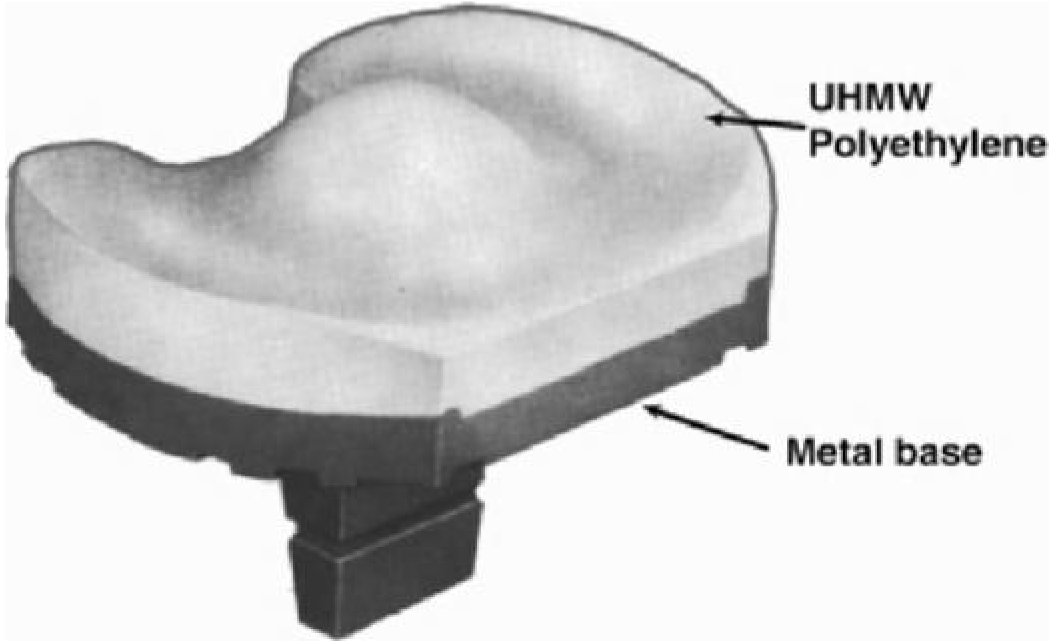

Femoral
surfaces
removed
Femoral component
Tibia


Knee Femoral
Component
Polyethylene
Articulating
Surface
Stemmed
Tibial Plate

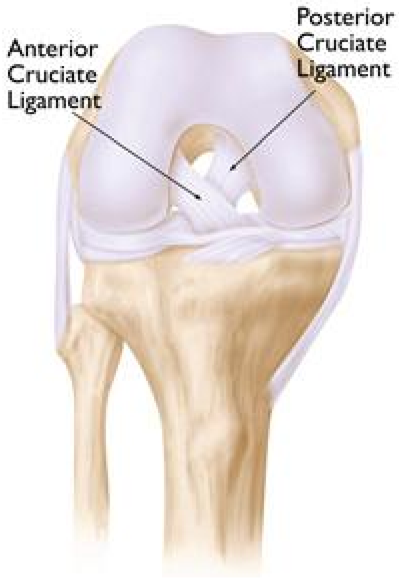

Femoral
component
Plastic
spacer
Tibial
component



- Total knee replacement surgery was first performed in 1968, and has evolved over the years into a reliable and effective way to relieve disabling pain and allow patients to resume their active lives.



Posterior-Stabilized Designs



Special bar on femoral component

Tibial Component

The tibial component has a raised surface with an internal post that fits into a special bar (called a cam) in the femoral component. These components work together to do what the PCL does: prevent the thighbone from sliding forward too far on the shinbone when you bend your knee.

- **Cruciate retaining design**
- **Bicruciate design**
- **Partial or unicompartmental**
- **Total or bicompartmental**