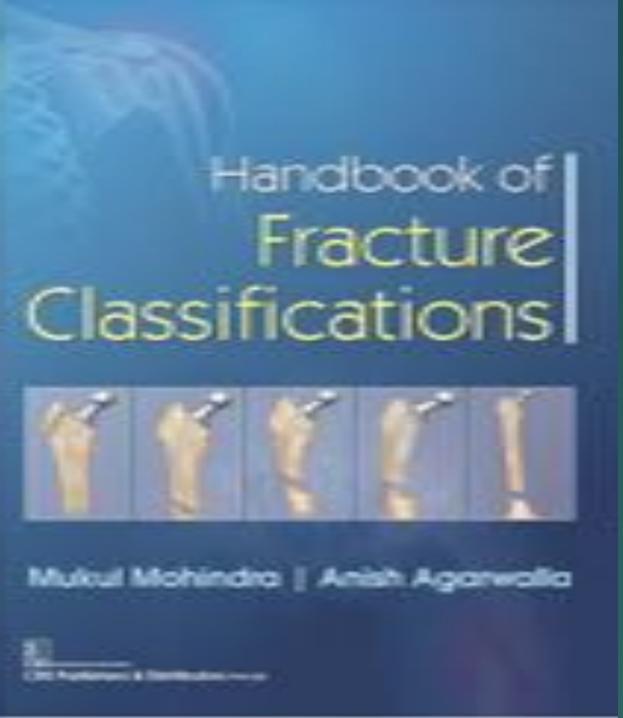
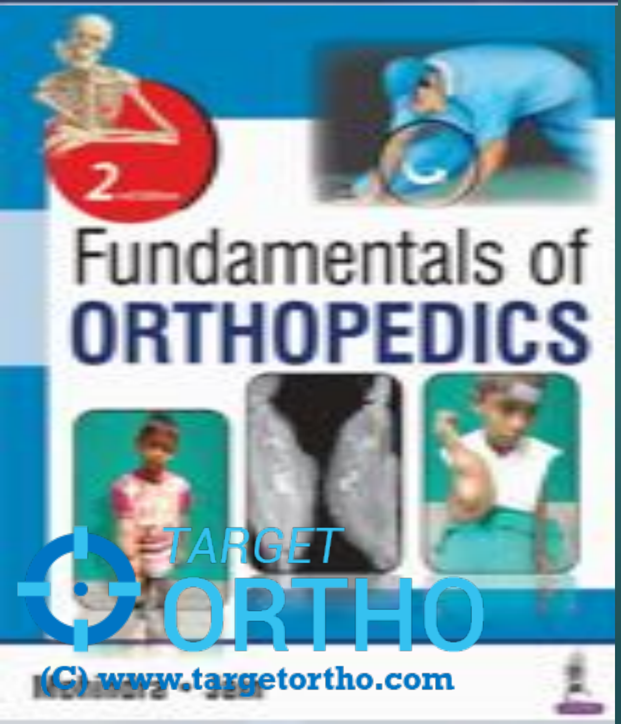




TOTAL HIP ARTHROPLASTY

Osteolysis $ Implant Loosening
(TRIBOLOGY)

M.S [Ortho], DNB, MNAMS
Dip. SICOT [Belgium]
FNB [Sports Medicine]
Fellowship in MIA, Athens [SICOT]

OSTEOLYSIS

Asymptomatic progressive osteolysis

↓

Should we operate ??

THE DEFINITIONS

TRIBOLOGY is the science how interacting surfaces and behave in relative motion.
It studies wear, friction and lubrication characteristics!

OSTEOLYSIS refers to progressive loss of bone tissue owing to a histiocytic response to wear debris

Overall, most common complication in THR and the most common cause of failure!

Aseptic loosening is the major complication and causes more than 70% of the revisions in hips in Sweden.

The Stages

OSTEOLYSIS

Generation of debris

Access to periprosthetic bone

Cellular response to debris

Prosthesis micromotion and dissemination of debris

Implant loosening and bone defects

Prevention

TARGET ORTHO

The Debris Generation!

wear rate is
0.1-0.5 mm/year

Polyethylene
(90% debris volume)

Cement

Metal/ Ceramics

0.025 to 0.050 mm/year

< 0.005 to mm/year

Particulate wear
(0.3 µm PE, 0.03 µm metals, 0.4 µm for ceramics)

Hip

Adhesive: Hard surface peeling off the softer one as microscopically PE sticks to Prosthesis.

Volumetric- over large area
Linear- over single contact point

Abrasive: Hard surface scraps off soft one (Cheese grater)

Knee

Delaminating: Formation of crevices or fissures in soft surface

Third body wear: Particles in joint space cause abrasion and wear

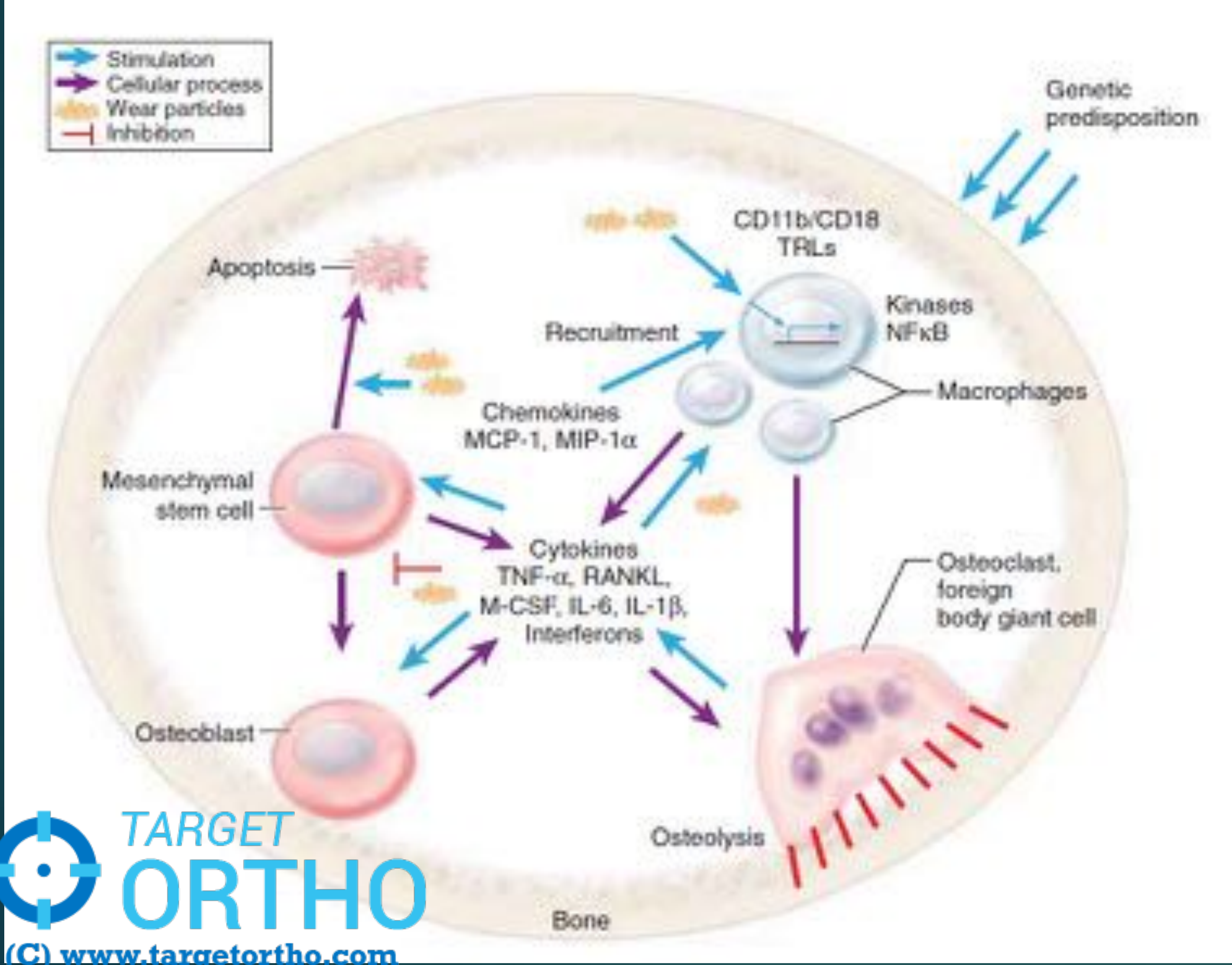
Periprosthetic access

Schmalzried, Jasty, and Harris described these areas of access as the "*effective joint space*,"

Path in the periprosthetic region accessible to the debris!!

This concept explains the development of osteolysis at the tip of a well-fixed femoral component with noncircumferential porous coating or over the dome of an acetabular component with holes in the metal backing.

Cellular response



Debris activate MACROPHAGES

Release of CYTOKINES

TNF-a, PGE-2, IL-1, IL-6,

Over expression of **RANKL**

MSC

Osteoblasts

Osteoclasts

Progressive bone loss around the prosthesis

Progressive Bone loss ⇔ Ongoing inflammatory response

Prosthesis micromotion

Hydrostatic pressure increased inside the joint (fluid accumulation)

dissemination of debris into the widened Effective Joint Space

Generation of PROGRESSIVE implant loosening and bone defects

Progressive osteolysis is another cause for reoperation, even in the absence of symptoms. If allowed to progress, revision becomes more complex or impossible.

Q. Best way to identify loosening

A. MRI

B. Bone scan

C. Radiostereometric analysis

D. Octreotide scan

Diagnosis

When there is "***Start Up Pain***"

Measurements are reported as the change in **bone mineral content (BMC)**

BMD Vs BMC: the area of the region of interest (ROI).

Collagen N terminal telopeptide elevated

BMD scans: Calculates periprosthetic bone density

Sensitive to Patient positioning

Bone Scan: Useful tool

Radiostereometric analysis *(the most accurate and precise technique); Used mainly for Research purpose!*

Ein Bild Rontgen Analyser

Precision 0.8 mm

Radiographic evidence mostly after 5 years!
*Check **serial clicks** every 3-6 months!*

EBRA-Digital measurement system is a method for measuring two-dimensional migration from digitized plain radiographs and consists of 2 software programs, EBRA-Cup and EBRA Femoral Component Analysis which operate within an image analysis software shell.

Three-phase bone scintigraphy pattern of loosening in uncemented hip prostheses

Domenico Rubello, Nicoletta Borsato, Franca Chierichetti, Pierluigi Zanco & Giorgio Ferlin

European Journal of Nuclear Medicine 22, 299–301 (1995) | Cite this article

The dynamic phase was invariably negative in both loosened and asymptomatic UHPs while markedly positive in the infected ones. The blood pool phase was positive to various degrees in 16 of the 26 loosened UHPs as well as in the infected UHPs, but was invariably negative in painless replacements. In the bone phase, areas of significantly (discrete to marked) increased uptake were observed in all the loosened prostheses as well as in two-thirds of the asymptomatic ones. However, *the regions of the lesser trochanter and/or tip and/or shaft were involved exclusively in the case of the loosened UHPs, and diffuse periprosthetic uptake was found only with loosened or infected implants*.

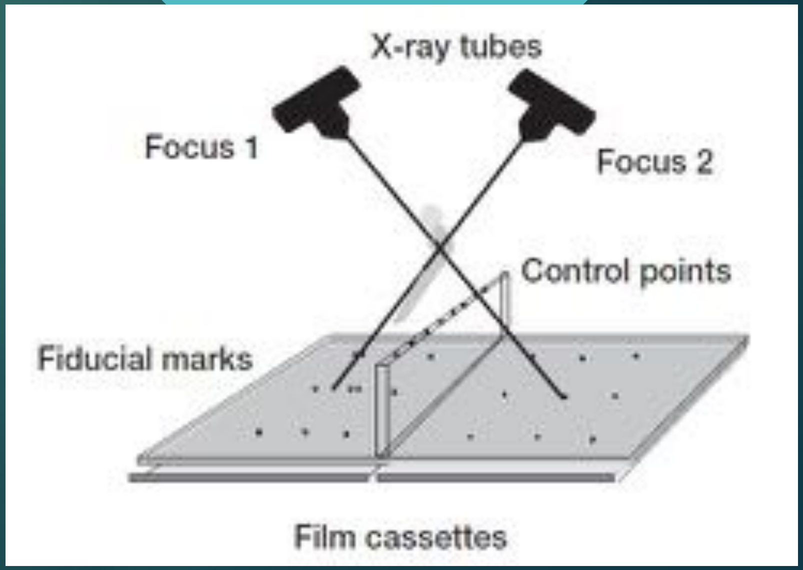
TARGET ORTHO

Springer Link

RSA

Uses radiopaque tantalum beads (1mm diameter) planted in the bone/ implant to follow the position of the components relative to the beads on radiographs!

The relative motions of the implant are calculated using the corresponding bone markers as a fixed reference segment. At least three well-spaced markers are identified in the implant and in the bone, and both translations and rotations are measured in different positions. Motion of an implant during a time period is named migration and value depicted.



Q. Regarding loosening of cemented femoral component, earliest findings occur at:

A. Loosening at cement bone interface

B. Loosening at stem cement interface

C. Not fixed, changes can be seen at either interface

D. Fractures occur within cement mantle first

Mnemonic

TARGET ORTHO

Q. Regarding loosening of cemented femoral component, earliest findings occur at:

A. Loosening at cement bone interface

B. Loosening at stem cement interface

C. Not fixed, changes can be seen at either interface

D. Fractures occur within cement mantle first

Femoral loosening commonly occurs at the stem-cement interface!

Acetabular loosening mostly occurs at the bone-cup interface!

TARGET ORTHO

Loosening of CEMENTED components

Lucencies > 2mm

Most commonly in lateral and anterior aspects of the femur

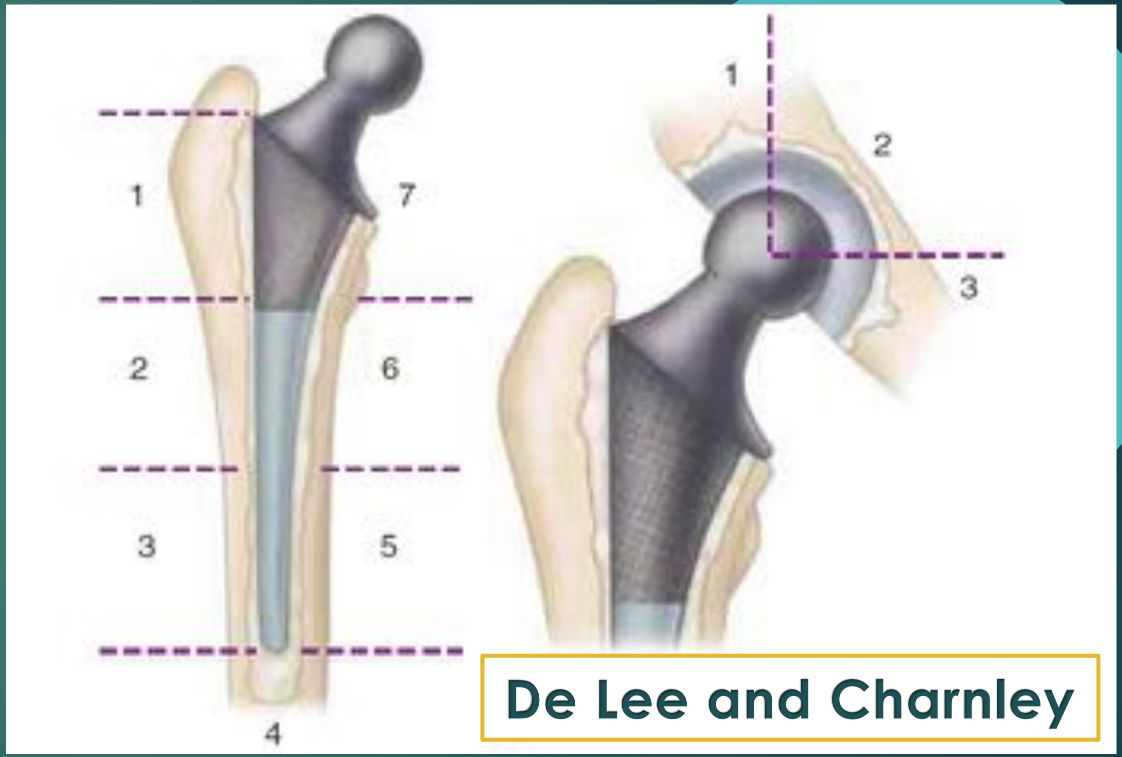
But not all lucencies !!!

Femoral canal widens 0.3mm/ year

↓

Radiolucent zones typically do not have the surrounding sclerotic line noted in loose femoral stems

Gruen'S zones



*The mechanical stability of the implant is determined by the overall degree of bone resorption at the **cement-bone interface**.*

(Path of least resistance)

Loosening of CEMENTLESS components

Fixation is classified as
Engh, Bobyn, and Glassman

(1) Bone ingrowth

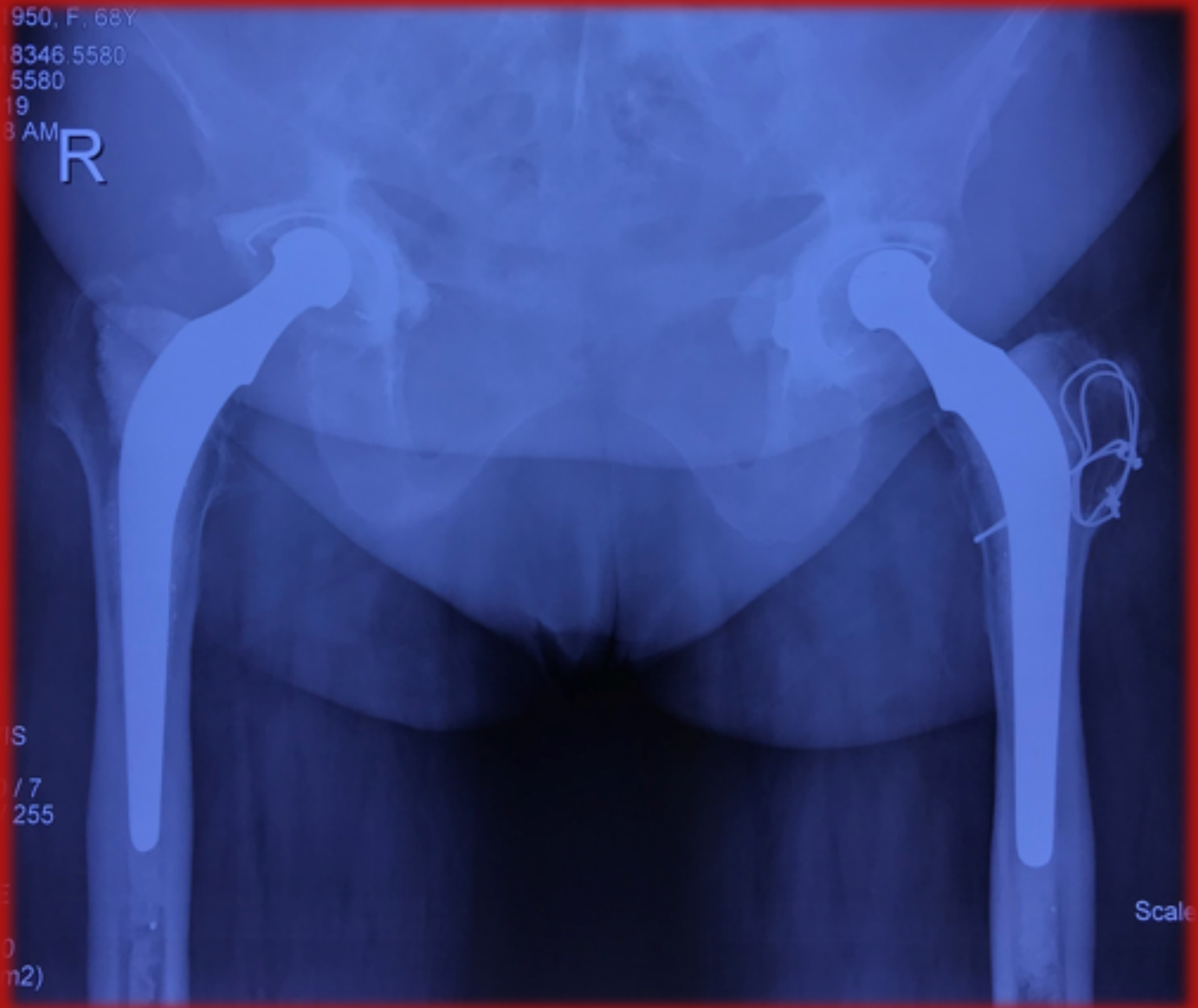
(2) Stable fibrous fixation

(3) Unstable

Fixation by bone ingrowth is defined as an implant with no subsidence and minimal or no radiopaque line formation around the stem. Most of the bone-implant interface seems stable. Cortical hypertrophy may be present at the distal end of the porous surface, and "spot welds" may be evident between the stem and endosteum. Variable degrees of proximal stress shielding can be seen.

An implant is considered to have stable fibrous ingrowth when no progressive migration occurs, but an extensive radiopaque line forms around the stem. These lines surround the stem in parallel fashion and are separated from the stem by a radiolucent space 1 mm wide. The femoral cortex shows no signs of local hypertrophy, suggesting that the surrounding shell of bone has a uniform load-carrying function.

An unstable implant is defined as one with definite evidence of progressive subsidence or migration within the canal and is at least partially surrounded by divergent radiopaque lines that are more widely separated from the stem at its extremities. Increased cortical density and thickening typically occur beneath the collar and at the end of the stem, indicating regions of local loading and lack of uniform stress transfer



TARGET ORTHO

Preventing Osteolysis

- Are any drugs also available ??
- Fixation technique ??
- Implant role ??
    - ❖ PE size
    - ❖ Head size

TARGET ORTHO

Preventing Osteolysis

Malalignment

(detrimental)

- Surgical and Fixation technique
- Role of Bisphosphonates, Denozumab and BMPs
- Right Implant factors
- Right Patient

Porous coating

Head size is most important determinant for volumetric wear. Femoral head size between 22 and 46mm in diameter does not influence wear rates of UHMWPE!

PE minimum 6 mm thick

Do cemented femoral stems show less osteolysis that press fit stems?

- some authors postulate that cement is a more reliable barrier to migration of wear debris down the medullary canal as compared to press fit components.

- depending on the data being examined, osteolysis may occur in up to 10-30% of femoral stems inserted without cement as compared to a prevalence of just 1 to 2% using modern and appropriate cementing techniques.

- with press fit designs some authors feel that circumferential press fit stems offer more reliable protection against wear debris as compared to non-circumferential designs; porous coating may provide a barrier to migration of wear debris.

Appropriate cementing

Fundamentals of Orthopedics

Table 19.1: Mixing techniques

First generation	Hand mixing of cement, it is put in the canal by a finger
Second generation	The femoral canal is prepared by brush and made dry. Cement restrictor is inserted into the canal and then cement is put using cement gun
Third generation	Vacuum-mixing of the cement to reduce cement porosity Pulsatile lavage of bone surfaces and femoral canal Cement pressurization for better bone penetration
Fourth generation	The prosthesis is inserted using distal and proximal centralizers to ensure an even cement mantle

Barrack, Mulroy, and Harris grading system for the femoral component cement mantle!

Grade A: Complete filling of the medullary canal without radiolucencies (“white-out”)

Grade B: Slight radiolucency at the bone-cement interface (<50%) is grade B.

Grade C: Lucency surrounding 50% to 99% of the interface or any cement mantle defect.

Grade D: Complete lucency on any projection or a defect of the mantle at the tip of the stem .

Grade C and D mantles have been associated with increased risk of loosening!

CEMENTED STEM TYPES in THR

Disadv.: No bond b/w bone & cement so if subsidence occurs → Loosening res

Disadv.: Sets up hoop stresses proximally that can cause fractures

Roughened surface
↓
Sets bond b/w cement & stem
↓
So no Hoop stresses
(Advantage)

Stem subsides
↓
Taper (Wedging) gains hold in canal
↓
Stem fixes
Longer life
(Advantage)

Design	Force closed (taper-slip)	Shape closed (composite beam)
Surface Finish	Polished	Roughened/matt
Taper	+	+/−
Collar	−	+
Ridges/flanges/profiles	−	+

Preventing Osteolysis

- Are any drugs also available ??
- Fixation technique ??
- Implant role ??
  - PE – *Right one ???*
  - Head size

THE POLYETHYLENE (PE)

Q. Concentration of free radicals in HCLPE is reduced by all except

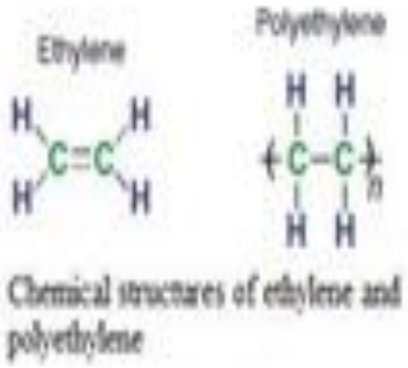
A. Remelting
B. Annealing
C. Vitamin E soaking
D. Ethylene oxide treatment

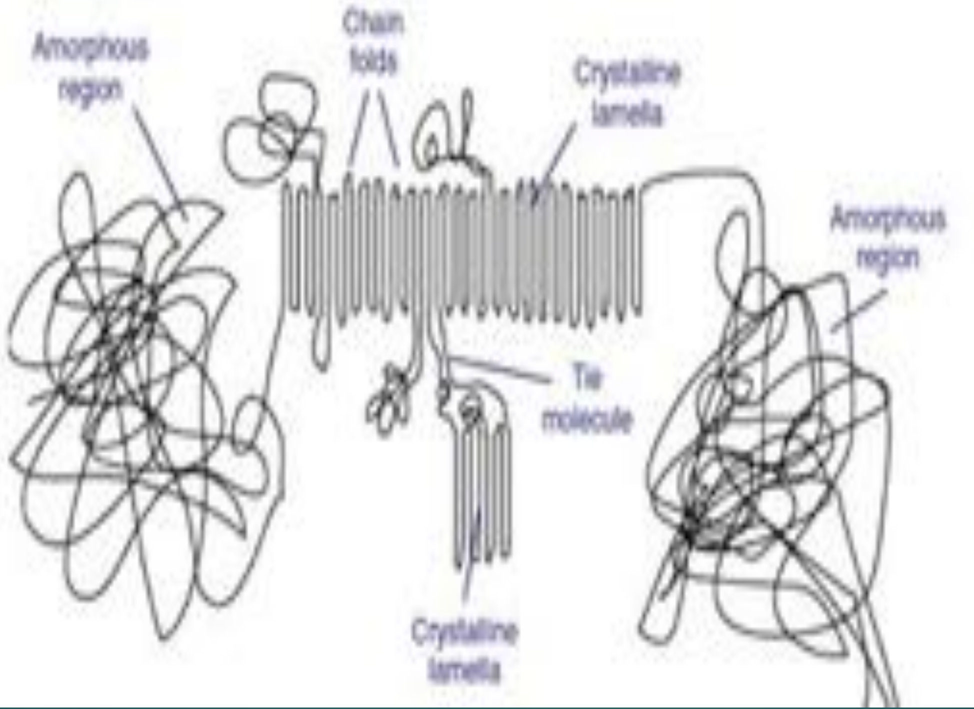
HCLPE- Highly cross linked PE

A form of High density PE

n: degree of polymerization; n > 2 lakhs

Chemical formula
$(-C_2H_4-)^n$





Polyethylene

Semicrystalline polymer

Crystalline *and* Amorphous phase

ThermoPlastic made from polymerization of **Ethylene gas** done at *high temp* (200-400°C) and *pressure* with *oxygen as catalyst*.

Low coefficient of friction, absorbs shock very well, has excellent chemical resistance and doesn't absorb moisture!

weak bonding between molecules allows local thermal excitations to disrupt the crystalline order → *Branching and Cross linking of chains*

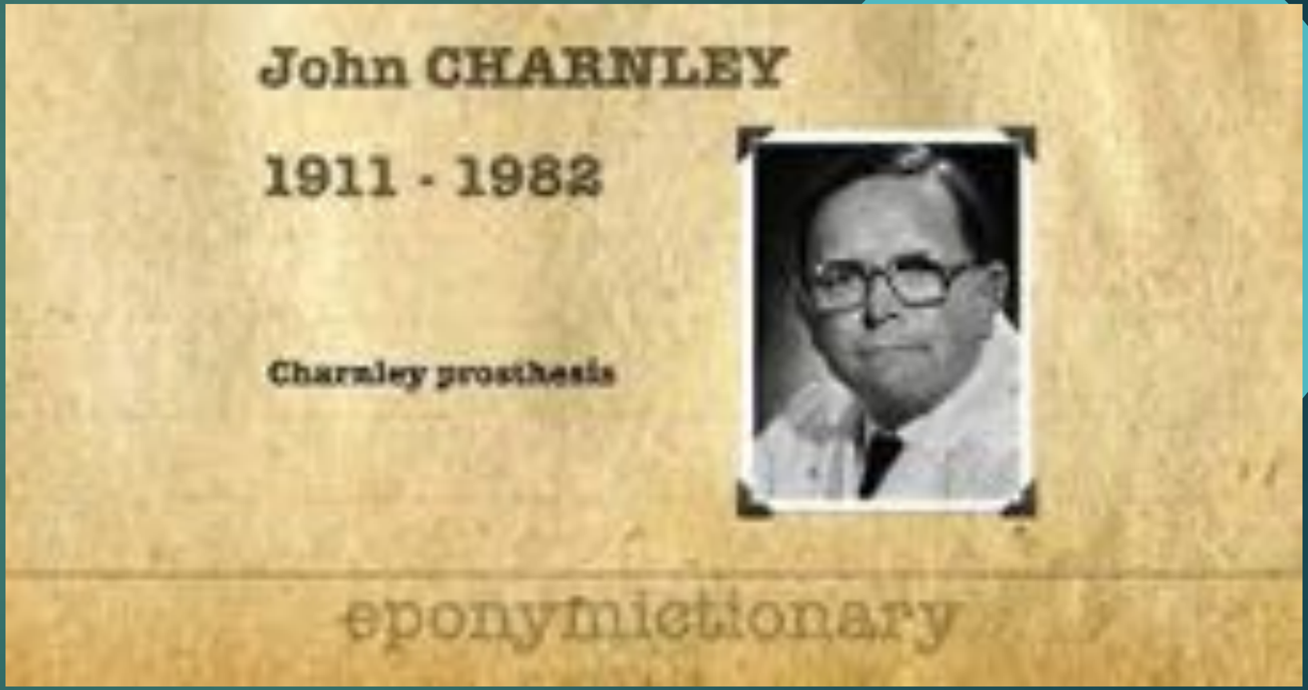
Low strength and high wear

UHMWPE

This material, with a molecular weight between 1-10 million, is less crystalline and less dense than high-density polyethylene and has exceptional mechanical properties. It is ***remarkably wear resistant AND has a very low coefficient of friction.***

The term UHMWPE designates that the average molecular weight is greater than 1 million g/mol

JOHN CHARNLEY



PE History

His (John Charnley) first prosthesis was made of a stainless-steel stem, fixed with acrylic cement, and a 22.2-mm diameter head coupled with a polytetrafluoroethylene (PTFE) cup

PTFE: Failure (1961)

(1962)

High-density "Polyethylene" (HDPE)

(R)uhr (CH)emie

(1990s)

Ultra-high molecular weight polyethylene (UHMWPE)

(G)Ranular (U)HMWPE (R)uhrchemie

+

Calcium stearate (lubricant to assist processing)

GUR 1050 and GUR 1020

UHMWPE

First generation

Sterlization

- Plasma sterilization
- Electron beam radiation
- Ethylene oxide treatment

Gamma irradiation (25-40 kGy)

Thermal energy → Free radicals

Crosslinking → Wear resistant

Remelting

Annealing

O_2 environment

Chain scission occurs and Free radicals form within the compound

Oxidative damage to PE

In vivo

Loss of crystallinity

makes PE soft (ductile)- loss of tensile strength and reduces hardness (decreases fracture toughness)

In Annealing, the polyethylene is heated to just below the material's melting temperature, and in Remelting, the polyethylene is heated to just above the melting temperature !

Second generation

- Use of sequential annealing steps (Dumbleton et al. 2006) where each step includes an irradiation process at 30 kGy followed by annealing at 130°C for 8 h (the total dosage of 90 kGy at the end of 3 sequential steps)
- High pressure crystallization (to increase crystallinity): *55–60% crystalline to 70%, so no fatigue cracks*
- Antioxidant soaks (Vitamin E)- acts synergistically with HPC and removes antioxidants
- Surface grafting with a biocompatible polymer (2-methacryloyloxyethyl phosphorylcholine: MPC) or, diamond-like coating (DLC)- Makes debris biologically inert
- *Removing calcium stearate (the lubricator)*

J Biomed Mater Res B Appl Biomater. 2009 Aug;90(2):720-9. doi: 10.1002/jbm.b.31340.

Effect of cross-link density on the high pressure crystallization of UHMWPE

Ebru Oral [1], Christine Godleski-Beckos, Bassem W Ghali, Andrew J Lozynsky, Orhun K Muratoglu

Affiliations + expand

PMID: 19213055 PMCID: PMC3065948 DOI: 10.1002/jbm.b.31340

HPC of uncross-linked UHMWPE has resulted in the formation of extended chain crystals and increased crystallinity, leading to improved strength.

PubMed.gov

Third generation

- Better Heat and Pressure treatments:
  - **Solid State Deformation** by *Compression Moulding* or *Ram Extrusion*- Extremely smooth surface finish obtained with a complete absence of machining marks at the articulating surface

Mechanical deformation enhances strength of polyethylene by orienting crystalline planes with respect to the principal deformation axes!

Resin powder
↓
Sheets/ Rods
↓
Final machined shape

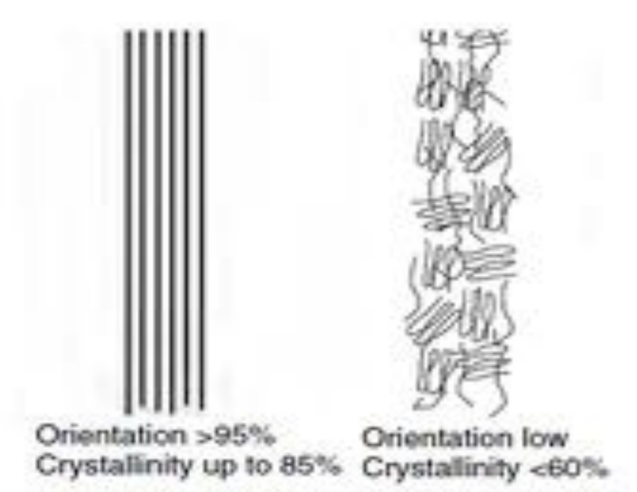


Figure 2: Macromolecular orientation of HPPE and PE

- Shifting from gamma sterilization in air to electron beam or gamma sterilization in a low-oxygen environment

- Removing Calcium stearate (the lubricator)

> Biomaterials. 2006 Jan;27(1):24-34. doi: 10.1016/j.biomaterials.2005.05.102.

Anisotropy and oxidative resistance of highly crosslinked UHMWPE after deformation processing by solid-state ram extrusion

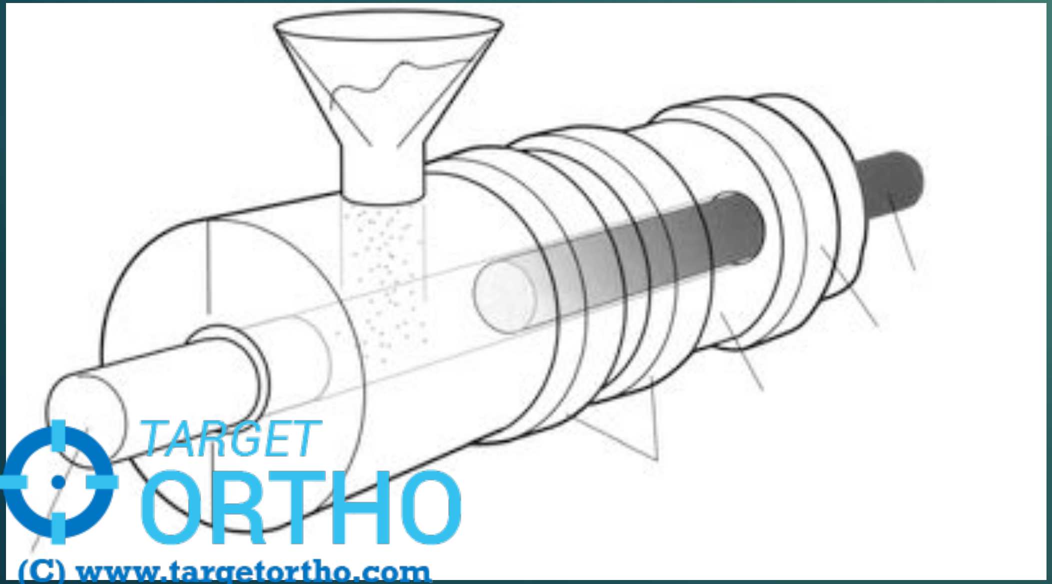
Steven M Kurtz [1], Dan Mazzucco, Clare M Rimnac, Dave Schroeder

PubMed.gov

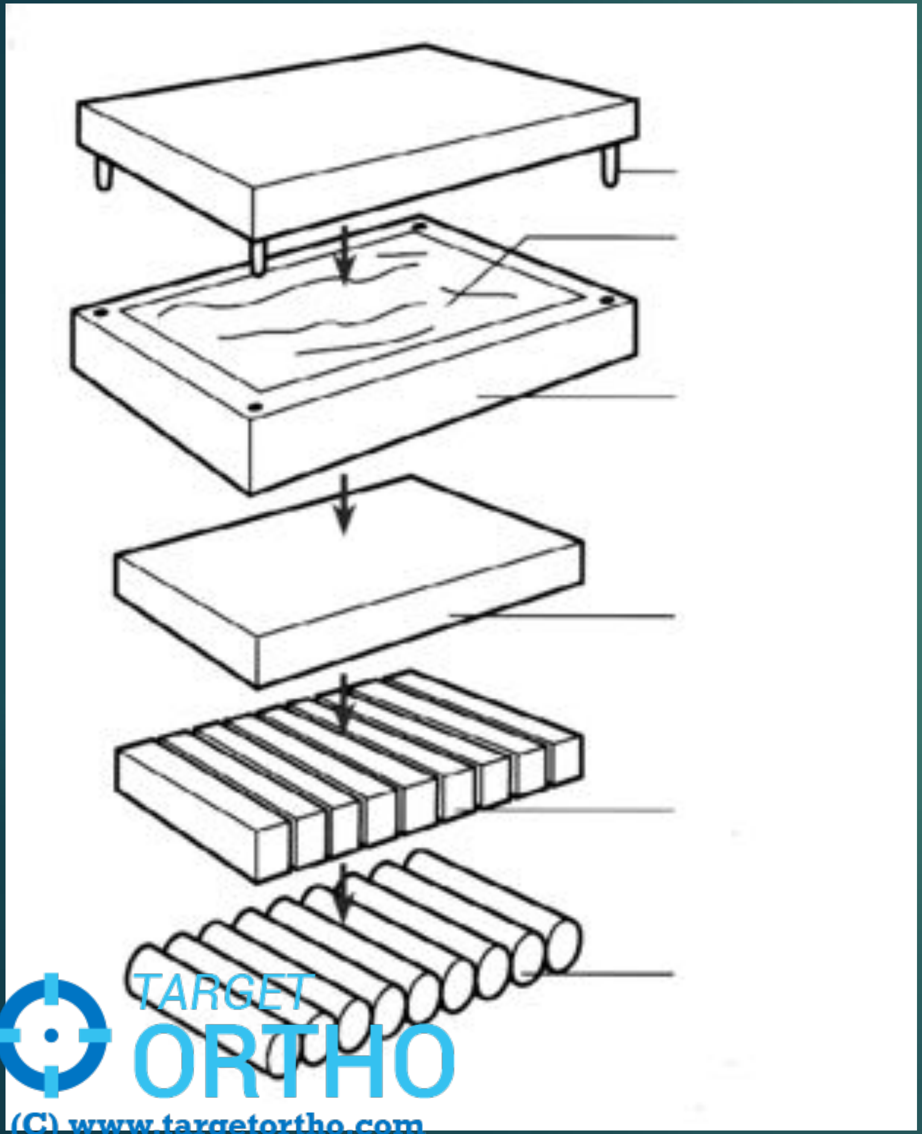
The highly crosslinked material contains detectable free radicals, at a concentration that is 90% less than control, gamma inert sterilized UHMWPE

Ram Extrusion

A measured quantity of polyethylene powder is introduced into a chamber. The powder is then pushed into a heated cylindrical barrel by a ram. As the ram retracts, the chamber is refilled with powder. As the process continues, each stroke of the ram advances the polyethylene through the heated barrel where the powder is consolidated into a continuous round bar. The implant is then machined from the bar stock.



Compression Moulding



In *compression moulding,* the raw polyethylene powder is moulded into large sheets. The powder is introduced into a cavity which is then heated as a platen covers the entire cavity and applies extreme pressure to the material for a specified time. The resulting sheets are cut into smaller blocks or section and turned on a lathe to form cylindrical bars from which the implants are machined.

Pinnacle ALTRX Polyethylene; DePuy Synthes

a mean wear rate of 0.02 mm/year

The manufacturing process uses a base resin bar stock of GUR 1020 moderately cross-linked at 7.5 megarads (Mrad).

This results in a cross-link density of 0.143 and is followed by remelting at 155^{o}C in an oxygen-free, argon convection environment to minimize free radicals.

Table 2. Currently available highly crosslink polyethylene liners

	Manufacturer	Radiation temp (°C)	Radiation dose (kGy)	Radiation type	Postirradiation thermal treatment	Sterilization method
Longevity	Zimmer	RT	100	E-beam	Melted at 150°C	Gas plasma
Durasul	Zimmer	125	95	E-beam	Melted at 150°C	EtO
Marathon	Depuy/J&J	RT	50	Gamma	Melted at 155°C	Gas plasma
XLPE	Smith&Nephew	RT	100	Gamma	Melted at 150°C	EtO
Crossfire	Stryker/Osteonics/ Howmedica	RT	75	Gamma	Annealed at 120°C	Gamma (30 kGy) in N_2
Aeonian	Kyocera	RT	35	Gamma	Annealed at 110°C	Gamma (25–40 kGy) in N_2

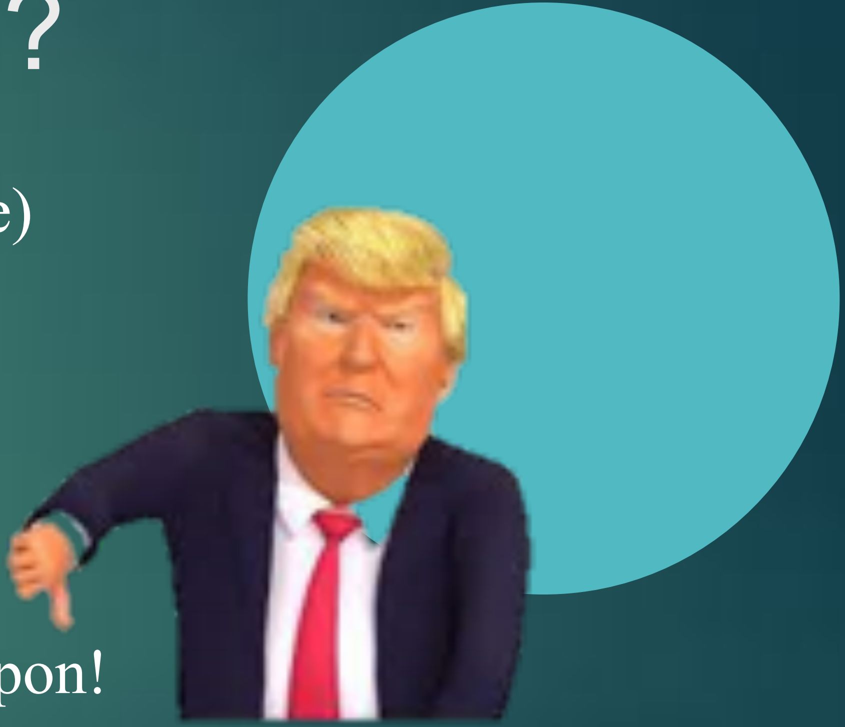
What if NO Polyethylene ?

A. Polyacetal (polymethylene oxide)

B. Polytetrafluroethylene

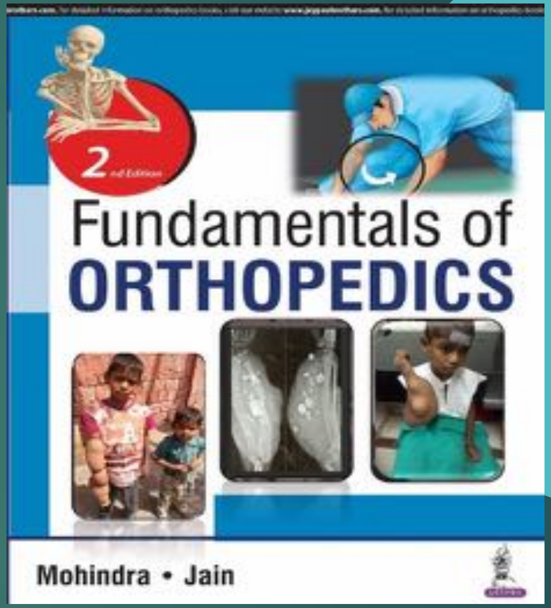
C. Polyether ether ketone

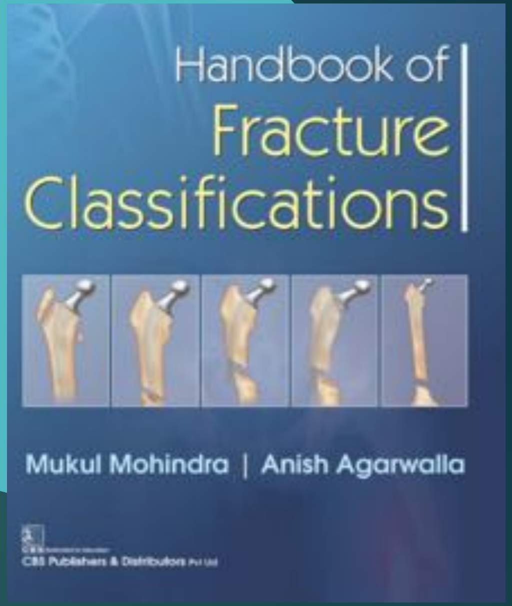
D. Nothing else being researched upon!



MUKUL MOHINDRA

M.S [Ortho], DNB, MNAMS
Dip. SICOT [Belgium]
FNB [Sports Medicine]
Fellowship in MIA, Athens [SICOT]





TARGET ORTHO