Commonly Used Orthopaedics Biomaterials

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Introduction

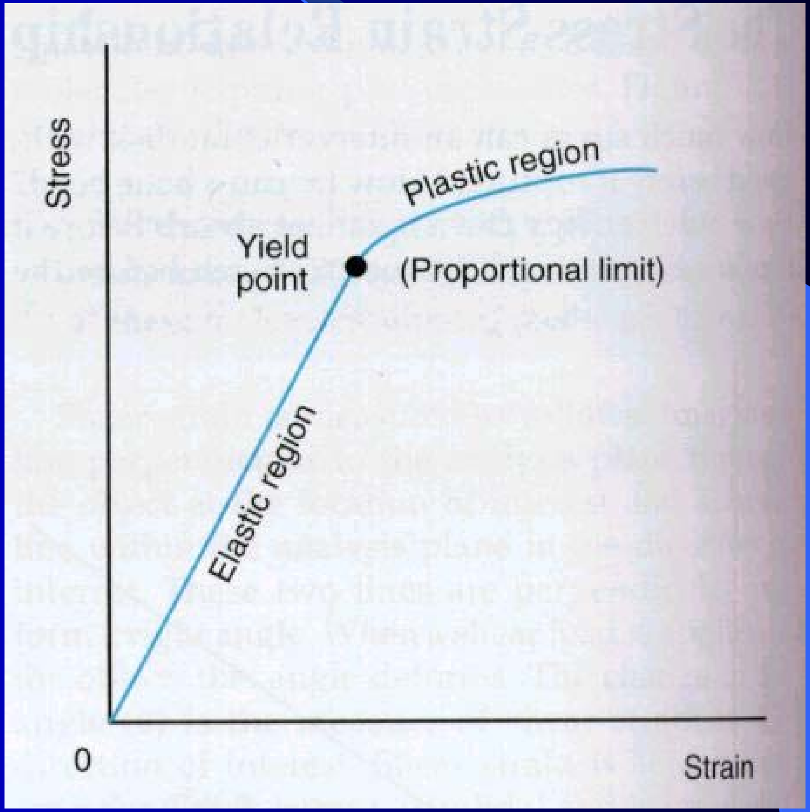
- Modern Orthopaedics is an Example of the Coopeartion in the Medical & Physical Sciences.
- Practitioner must have A Knowledge of Physical Sciences & Engineering Principles.

Introduction (Cont)

- Bone Response to Mechanical Stress is Related to the Mechanical Properties of Tissues.
- Fracture Sites Has no Tensile Strength at the Time of Injury.

Basic Concepts

- **Young's Modulus (Elastic Modulus)** The ratio of stress to Strain; slope of the elastic region of the stress-strain curve for a material.



Basic Concepts

- **Young's Modulus Tensile, Compression.**
- **Shear Modulus Pure Shear.**
  (modulus of rigidity)

Basic Concepts (Cont)

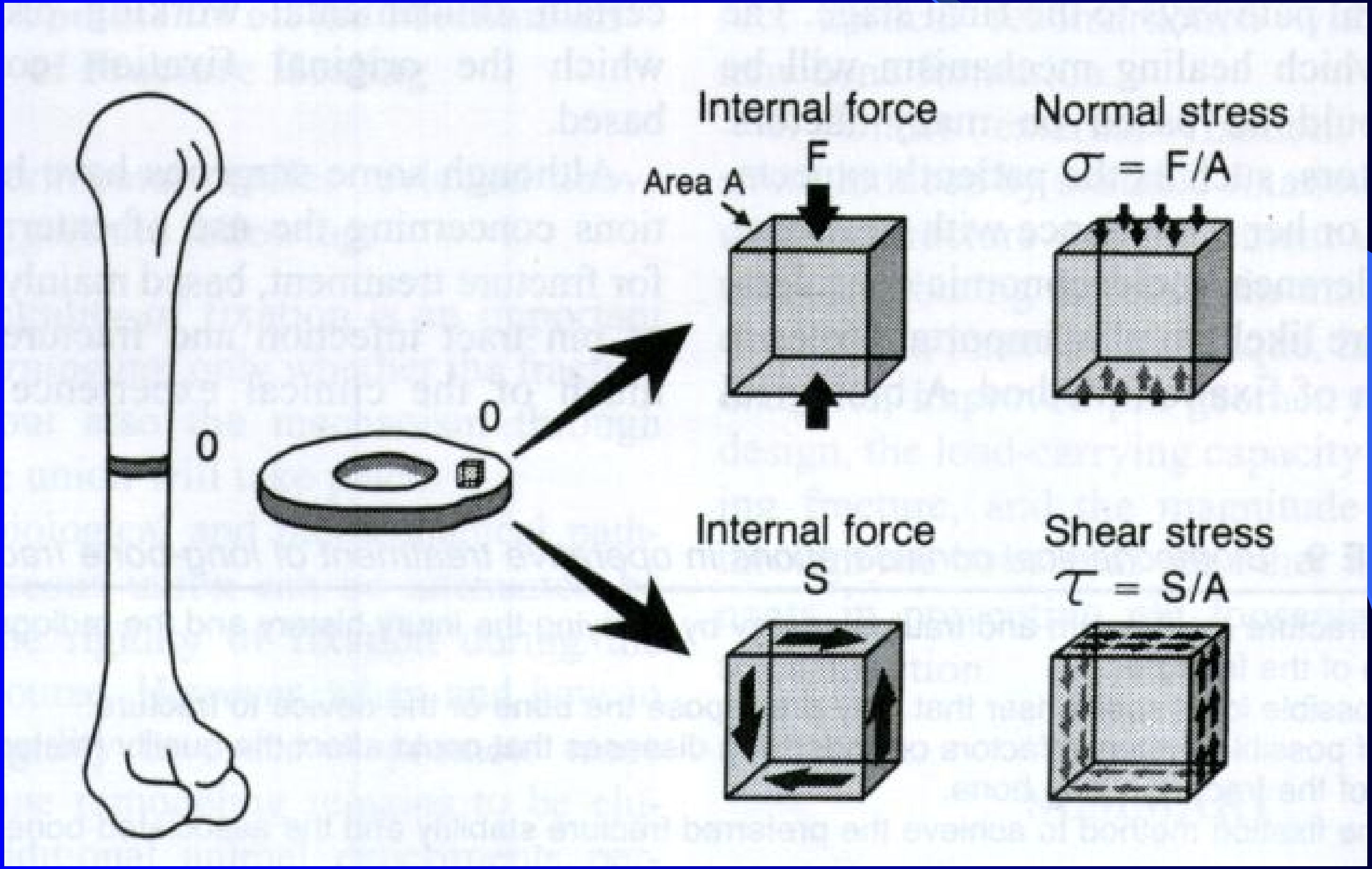
- **Normal Stress**.

The intensity of the internal forces normal to a plane passing through a point in the body.

- **Shear Stress**.

The intensity of the internal forces parallel to a plane passing through a point in the body.

Basic Concepts (Cont)

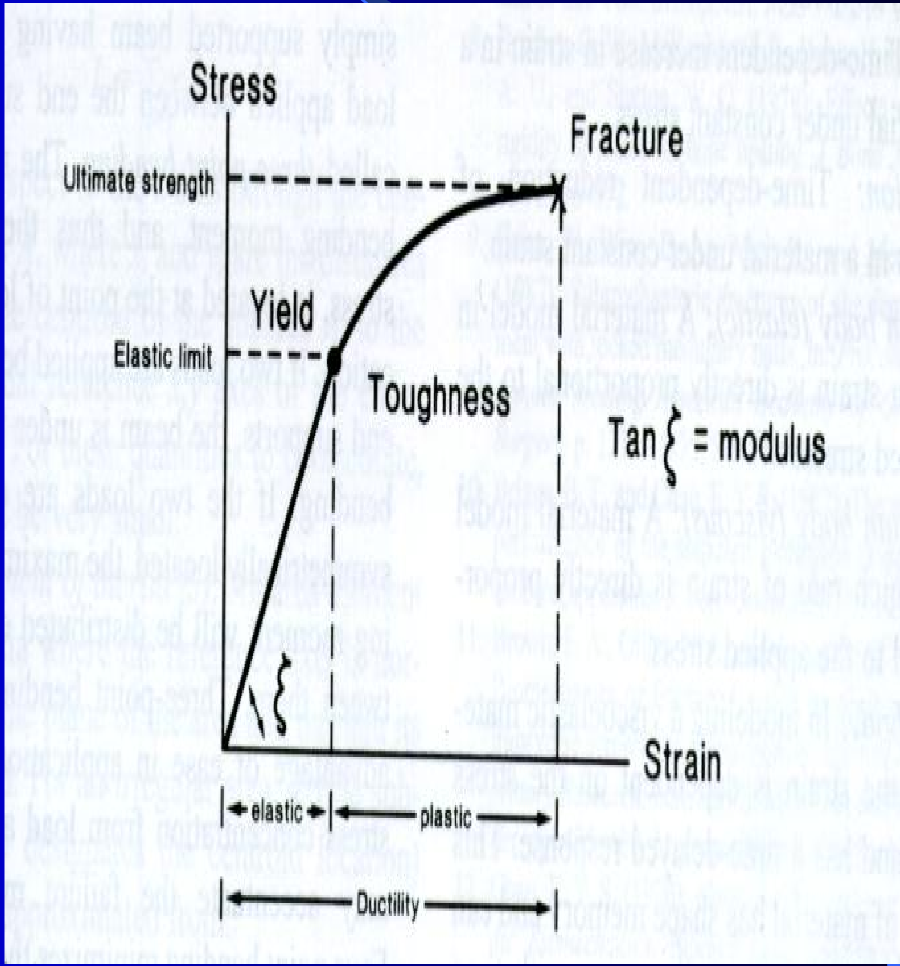


Basic Concepts (Cont)

- **Ultimate Tensile Strength.**

The maximum attainable stress of a material.

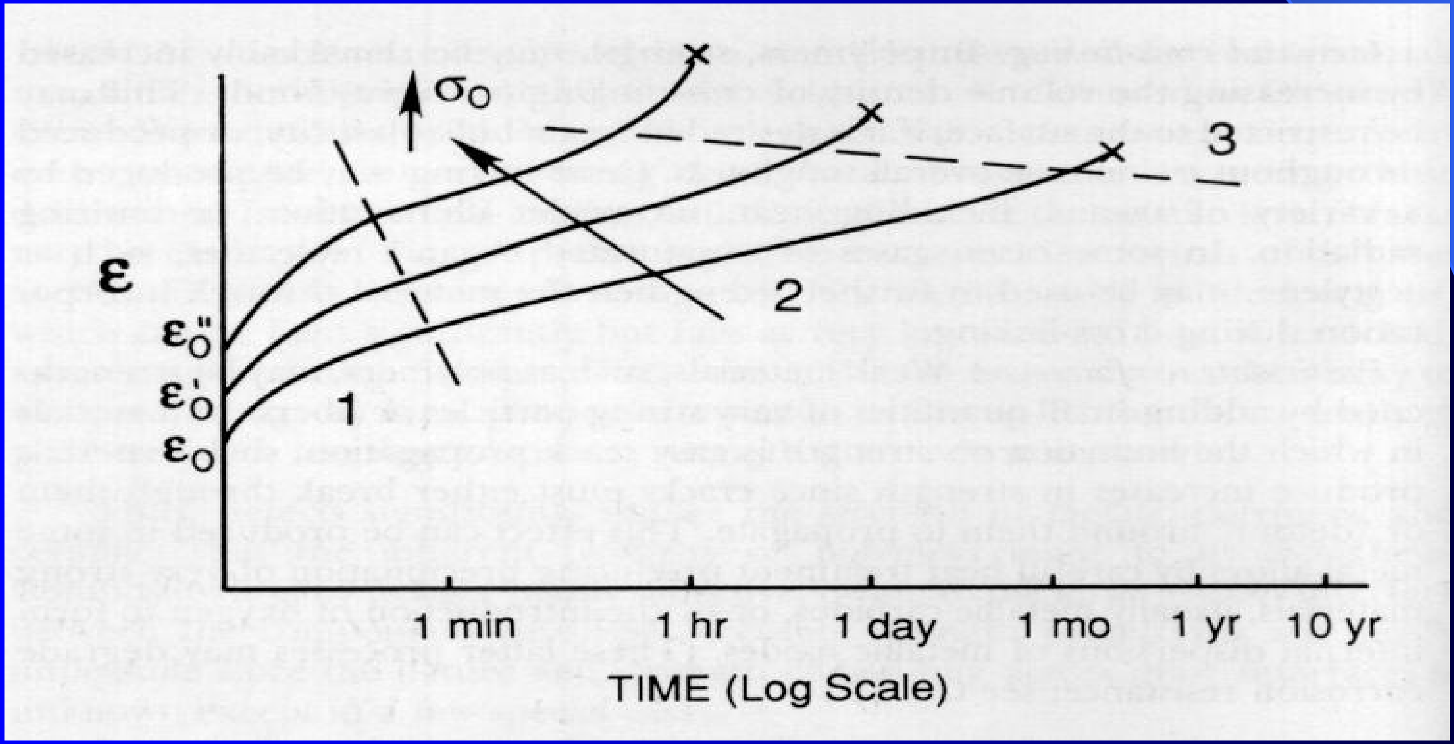
$\sigma_u \leq \sigma_m$



Basic Concepts (Cont)

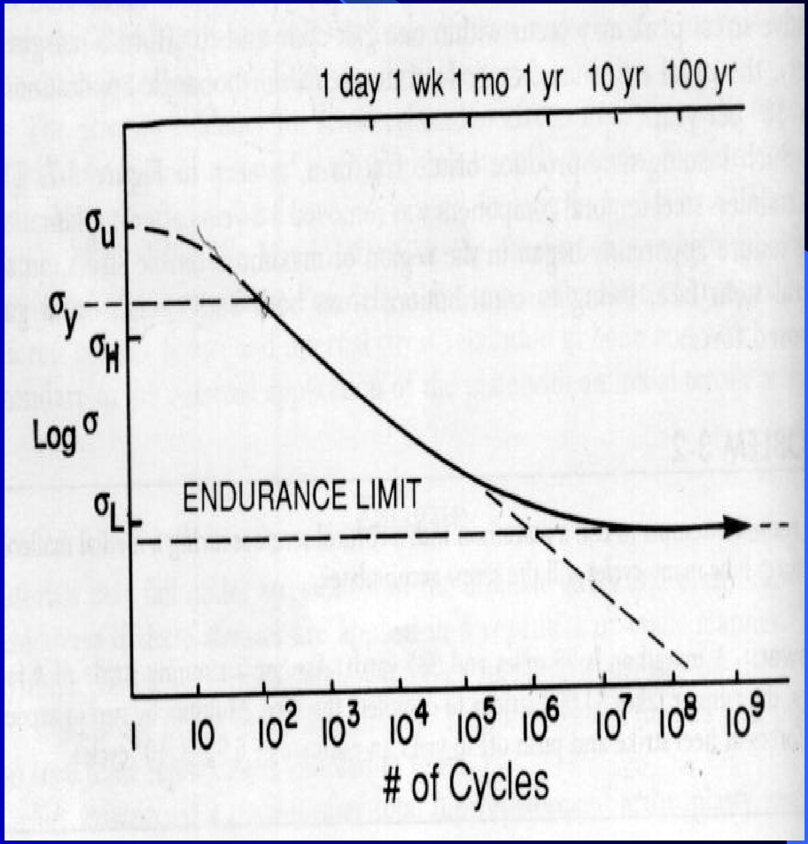
- **Creep**

Deformation under constant load.



Basic Concepts (Cont)

- **Endurance Limit.** The stress level below which no fracture can occur regardless of the number of loading cycles applied.



Mechanical Properties of Bone

- Young's Modulus (E) 17.0 GN/m^2
- Ultimate Tensile Strength (UTS)

  0.132 GN/m^2
- Compressive Strength (σ_c) 0.192 GN/m^2
- Shear Modulus (K) 2.01 GN/m^2
- Poisson's Ratio (ν) 0.3

Implant

Success of an Implant is Determined by:

- Conditions of Patient.
- Surgeon Technical Skills.
- Biocompatibility of Implant.
- Mechanical Properties.
- Wear / Corrosion Resistance.

Other Properties That Affect Choices Between Materials.

- Abrasive Resistance.
- Creep Rate.
- Coefficient of Friction.
- Endurance Limit.
- Effect of Degradation Product.

Biocompatibility

State of Mutual Coexistance between a Biomaterial and the Physiological Environment Such as Neither has an Undesirable Effect on the Other.

Implant Materials

- Metals.
- Ceramics.
- Polymers.

Implant Materials (Cont)

- Success of Total Joint Replacement is Directly Related to the Ability to Transfer the Load Uniformly from the Components to all Surrounding Bone.

- A Region of the Bone Which is Unloaded by the Presence of the Prosthetic Components Will Undergo Resorption (Wolf).

Implant Materials (Cont)

- Bone Resorption Will Lead to Loosening and Eventually Loss of Functionality of Prostheses.

Fixation

Fixation is the coupling of prosthetic components to the musculoskeletal system so that prosthetic and natural elements may act together in a harmonious manner

Goals of Fixation

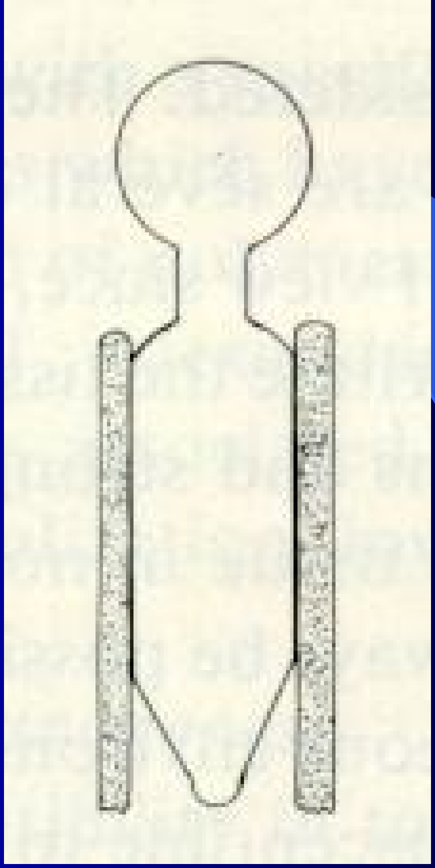
- Elimination of relative motion between loaded implant and supporting bone.
- Production of contact stresses on bone within normal (acceptable limit).

Goals of Fixation (Cont)

- Maintenance of resultant stresses in bone close to the normal physiologic pre-implantation level, to minimize bony adaptation remodeling.

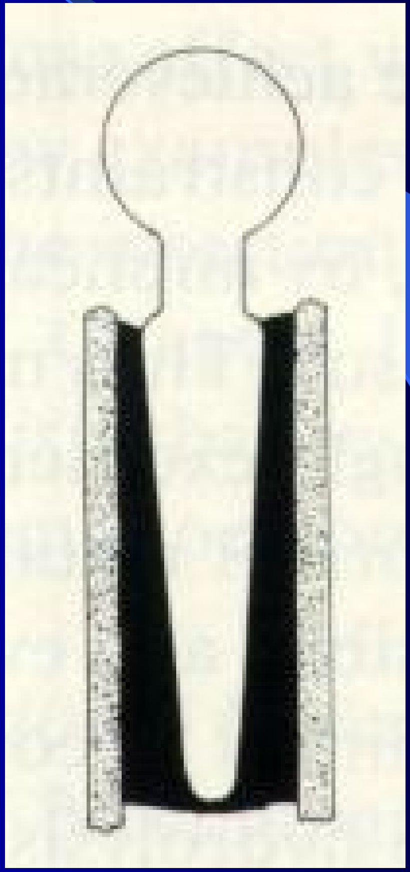
Types of Fixation

- Direct Interface Fit.



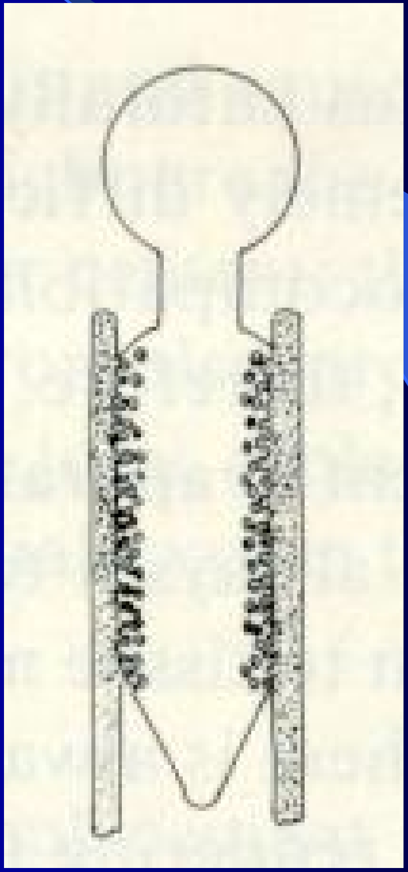
Types of Fixation (Cont)

- Cement or Grouting agent.
- Most Popular.



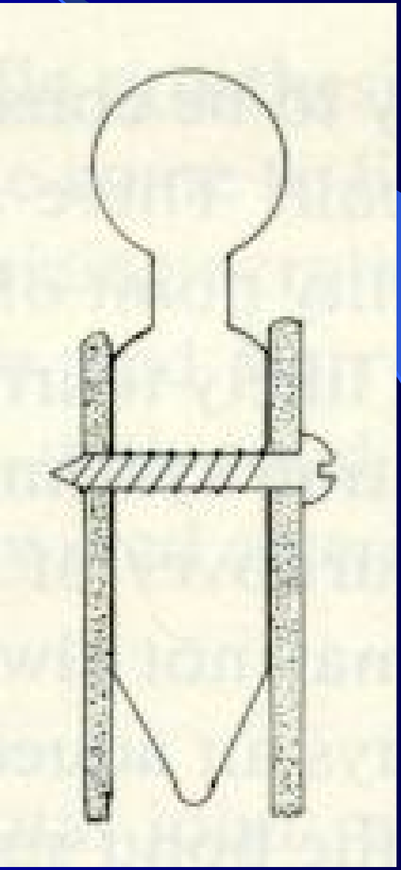
Types of Fixation (Cont)

- Ingrown Fixation by tissue growth into porous portions of coated stem. Such as cobalt-base coating on cobalt-base alloy device.



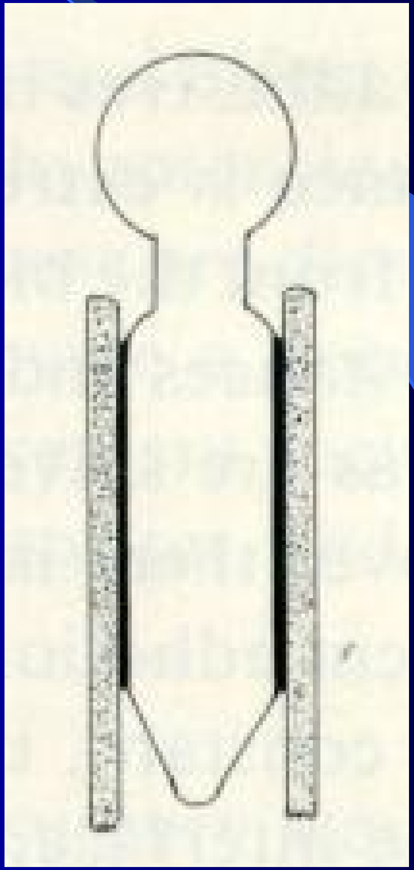
Types of Fixation (Cont)

- Mechanical Fastener



Types of Fixation (Cont)

- Adhesion.



Fixation Devices

Rigid Devices. Healing is Accomplished by Slow Remodeling.
(Disuse Atrophy Due to Device Rigidity Results in Weakening of the Bone & the Risk of Refracture at Removal.
(With You There, Why Should I) Leo's Law
Bone response to rigid fixation.

Fixation Devices (Cont)

Load (L)

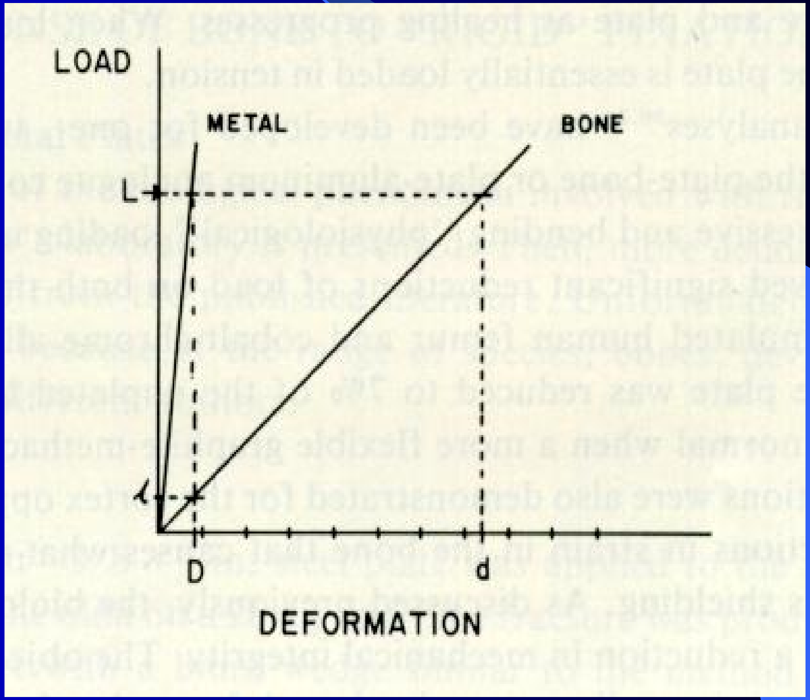
Bone deformation = d

Plate deformation = D

Bone & Plate coupled together.

Deformation = D

Load is reduced to l



Fixation Devices (Cont)

- The Reduction of Load Carried by Bone was Measured to be 72% - 84%

Metals

- Are Rigid Devices.
- Are Widely Used in Orthopaedics.
- Are Load Bearing Materials.
- Are Used in Devices such as:
    - Fracture Fixation.
    - Joint Replacement.
- Have High Tensile & Compressive Modulus.
- Have Reasonable Elastic Ranges.

Metals (Cont)

- Have Sufficient Plastic Deformation.

(this allows bending before catastrophic failure).

- Have Excellent Resistance to Environments Such as:

    - Sterilization.
    - Implantation.

Metallic Alloys Used in Orthopaedic

- Stainless Steel 316L.
- Co-Cr-Mo.
- Ti-6AL-4V.

Mechanical Properties of Orthopaedic Alloys

Material	Elastic Modulus (GN/m^2)	Yield Strength (MN/m^2)	U.Tensile Strength (MN/m^2)
316L	200	795	965
Co-Cr-Mo	210	950	1450
Ti-6Al-4V	105	895	1173

Ceramics

- Ceramics are hard, brittle material.
- Ceramics Mechanical Properties are:
- Fracture Strength (comp) 4000 N/m^2
- Flexural Strength 400 N/m^2
- Young's Modulus 380,000 N/m^2
- Coefficient of Friction 0.05
- Wear Rate 400 mm/sec

Polymers.

- **Definition:**

Polymers (Macromolecules) are Long Chain Molecules Built up by Repetition of Small, Simple Chemical Units.

Polymers Contain:

- Carbon.
- Hydrogen.
- Oxygen.
- Nitrogen.
- Silicon.
- Sulfur.

Polymers (Cont)

- **Applications.**

Polymers Are Widely Used in Orthopaedics.

Some of its Applications Are:

- Cement or Luting Agents to Anchor Prosthese.

- Bearing Surfaces for Metal Parts.

- Spacing, Filling, Dynamic, Non-Load Bearing Implants.

- Charnly total hip.

Polymers (Cont)

- **UHMWPE**

Elastic Modulus. (GN/m^2)	1.04
Yield Strength. (MN/m^2)	12.4
Ultimate Tensile Strength. (MN/m^2)	38

Mechanical Properties of Polymethylmethacrylate (PMMA)

A solid, relatively flexible mantle between bone and prosthesis, when introduced in a doughy Phase.

Yield Strength

20.7 - 34.6 N/m^2

Tensile Strength

6.9 - 20.8 N/m^2

Flexural Strength

45 - 58 N/m^2

Shear Strength

32.5 – 40 N/m^2

Mechanical Properties of (Comparison)

Property	Highest	Intermediate	Lowest
Tensile modulus	Ceramic	Metals	Polymers
Yield strength	Metals	-	Polymers
Ultimate strength	Ceramics	Metals	polymers

Requirements for Joint Prosthesis Material

1. **Mechanical Requirements:**

    - high Yield & Fatigue Strength.

    - Modulus of Elasticity to Interface with Bone.

    - Wear Resistance.

Requirements for Joint Prosthesis Material (Cont)

2. **Chemical & Physical Requirements.**

- Low Rate of Corrosion.
- Low Susceptibility to Corrosion.
- Low Coefficient of Friction.

Requirements for Joint Prosthesis Material (Cont)

3. **Biological Requirements.**

- Not Induce Inflammatory Response.
- Absence of Tumorgenicity.
- Not Activate Immune System.

Material Components of Joints

Material Components of Joints Most Commonly Replaced by Commercially Available Prostheses.

Component	Alloy	Polymer	Ceramic
• Hip			
Femoral Head	316L Ti-6AL-4V Co-Cr-Mo	---	Alumina

Material Components of Joints (Cont)

Component	Alloy	Polymer	Ceramic
Femoral Stem	316L	---	--
	Ti-6AL-4V		
	Co-Cr-Mo		
	Co-Ni-Cr-Mo		

Material Components of Joints (Cont)

Component	Alloy	Polymer	Ceramic
• Knee			
Femoral	316L	---	--
Component	Co-Cr-Mo	---	--

Total Hip Replacement

John Charnley introduced two inventions:

1. **Adaptation of the low-friction principle**.

   A relatively small metal femoral head rotating against a polyethylene acetabular cup.

Total Hip Replacement (Cont)

2- **The use of Acrylic cement.**

(Polymethymethacrylate PMMA) as a filling material to accommodate uniform load transfer between prosthesis and the irregular texture of bone.

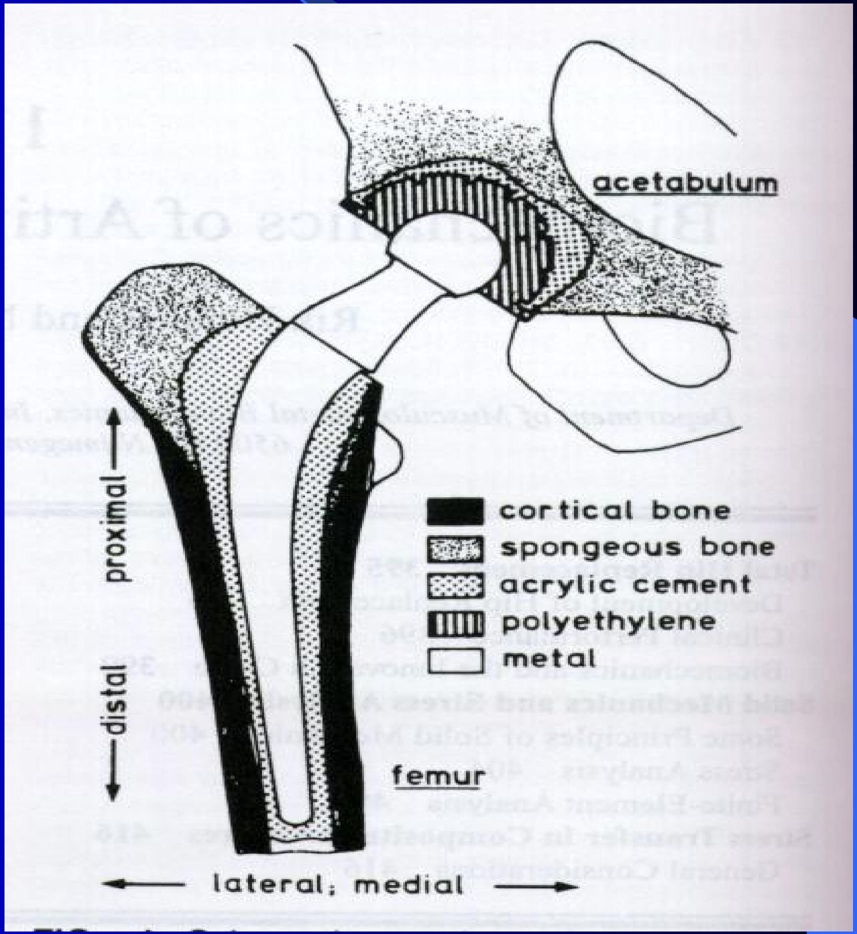
Total Hip Replacement (Cont)

Cemented

Charney

prosthesis

(From Huiskes)



Total Hip Replacement (Cont)

Problems with Cemented THR.

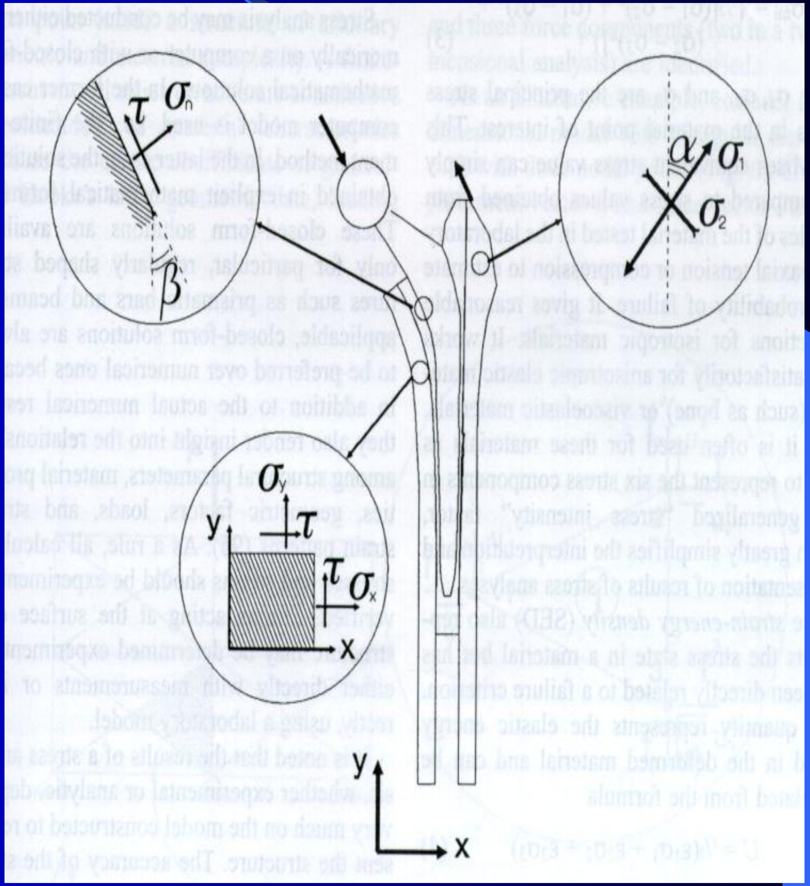
- PMMA is a relatively weak.
- Mechanical loosening (Aseptic) or long term.

Total Hip Replacement (Cont)

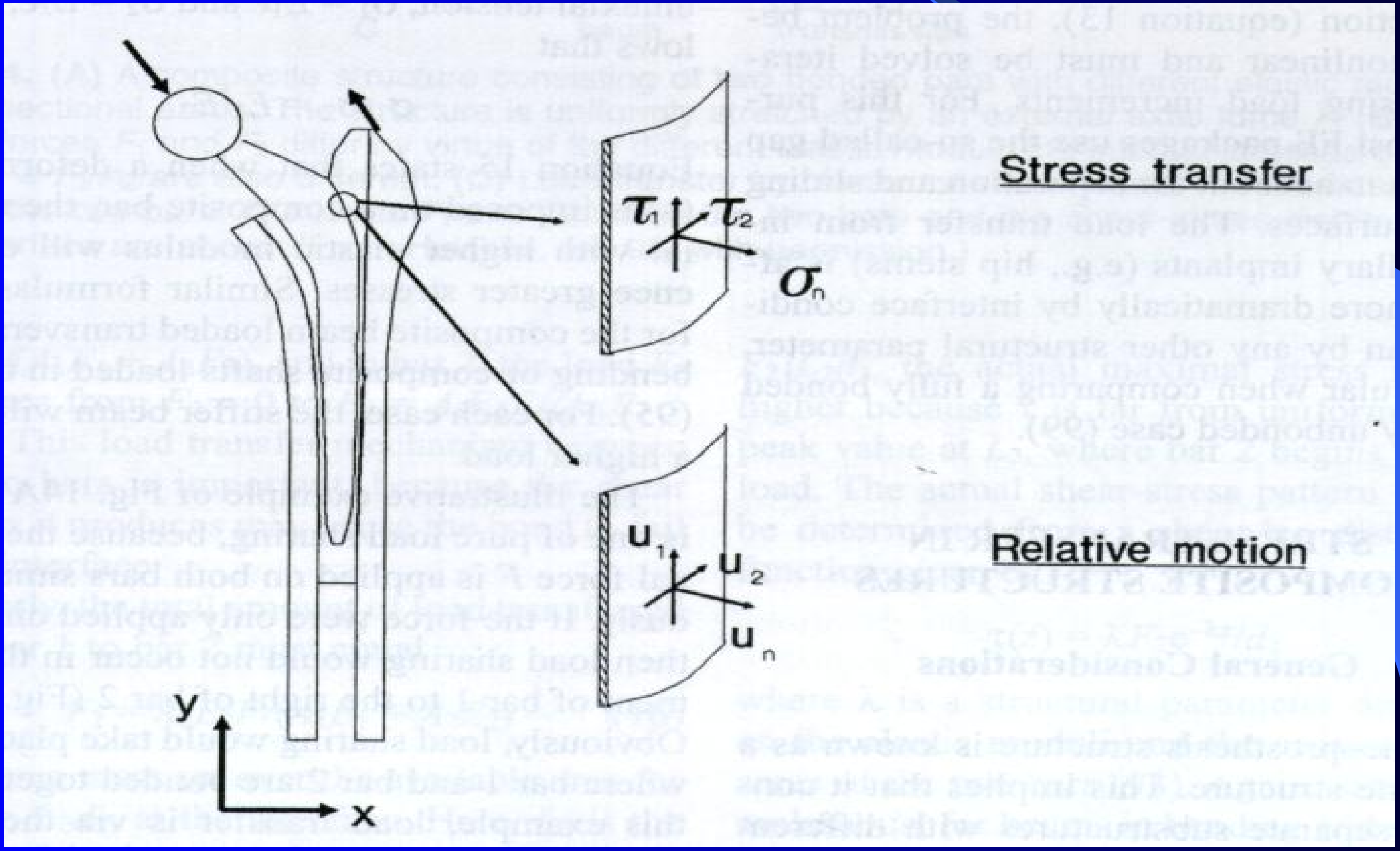
- Repeated application of load on the hip will create relative motion between bone and cement causing further resorption and loosening.

Total Hip Replacement (Cont)

- **Stresses State**



Total Hip Replacement (Cont)



Total Hip Replacement (Cont)

- High and frequent loads on the hip joint.
- 1 million cycle per year. This may cause fatigue failure.
- Average life span 10-20 years.

Total Hip Replacement (Cont)

Problems with Non-Cemented THR.

- Fixation relies on a good mechanical fit (no cement to fill the gaps between the prosthesis and bone).

Total Hip Replacement (Cont)

- Gaps at the implant-bone interface create routes for migrating wear debris, promoting long-term loosening.

Wear

- Is measured as the mass of material removed from interacting surfaces per unit of time or as the volume lost.

Wear (cont)

- Factors Affecting Wear Rate:

  - Stresses across the sliding interface.

  - Velocity of the sliding.

  - Roughness of the surfaces.

  - Lubricants.

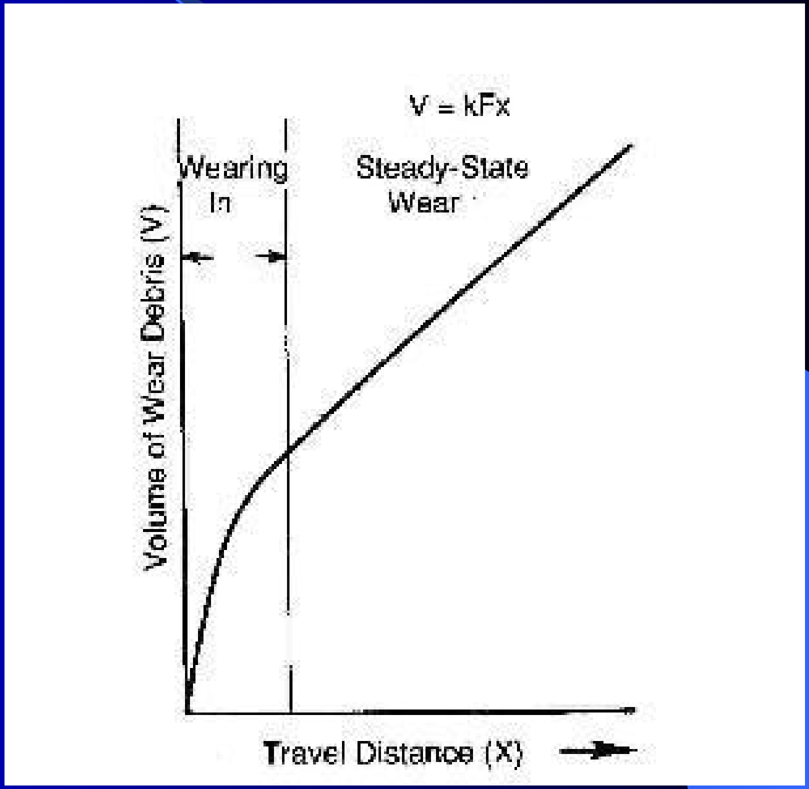
Wear (cont)

- Wear debris produced by all materials used in total joint replacement (TJR).

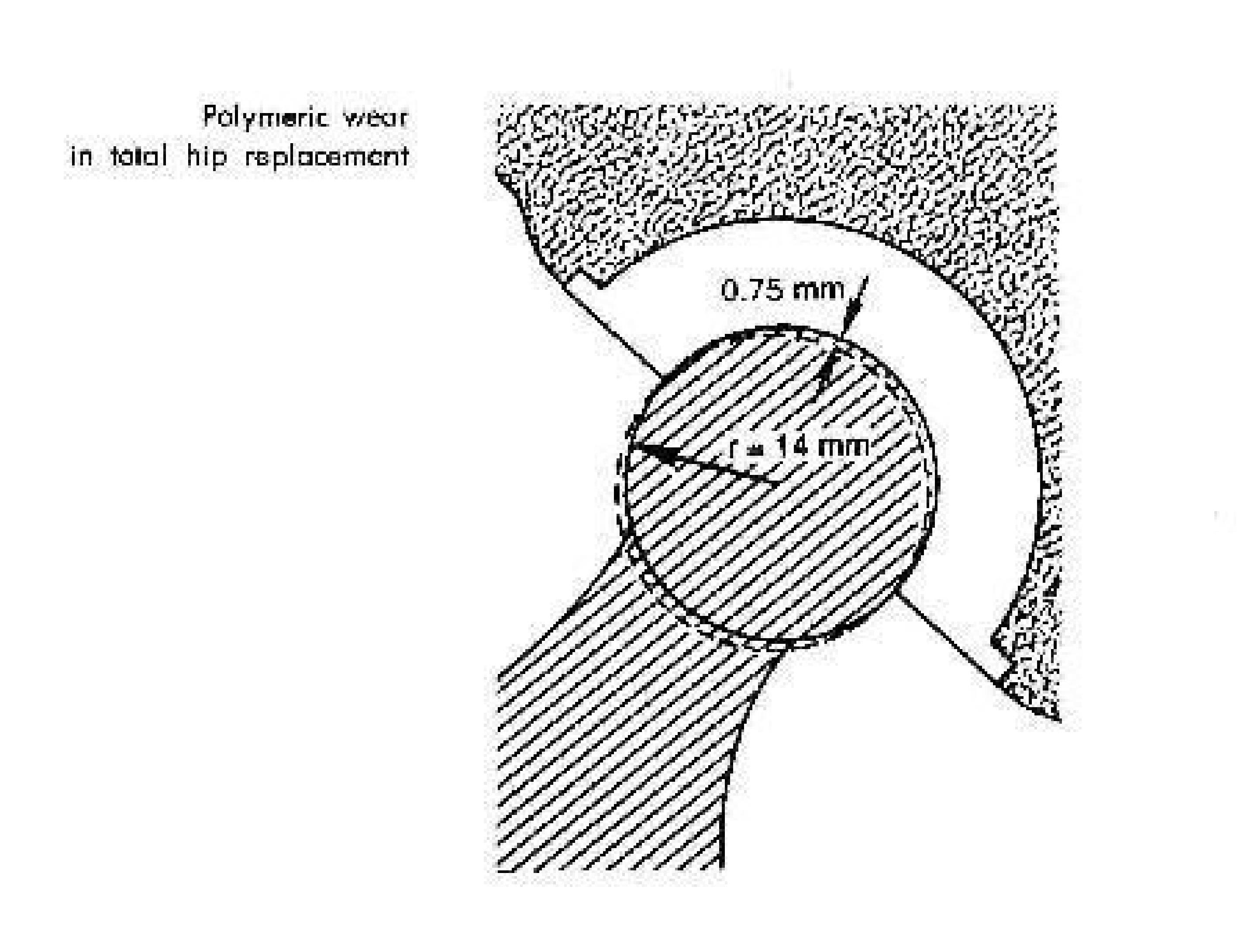
K : Material dependent.

F: Force across the articulating interface.

X: distance of relative travel.



Wear (cont)



Wear (Cont)

- Factors that influence the extent of polyethylene wear are:
  - Composition.
  - Roughness of articulating surfaces.
  - Implant design.
  - Weight and activity of the patient.

Wear (Cont)

Concentration of wear particles in tissues adjacent to painful or loose prostheses. (ppm)

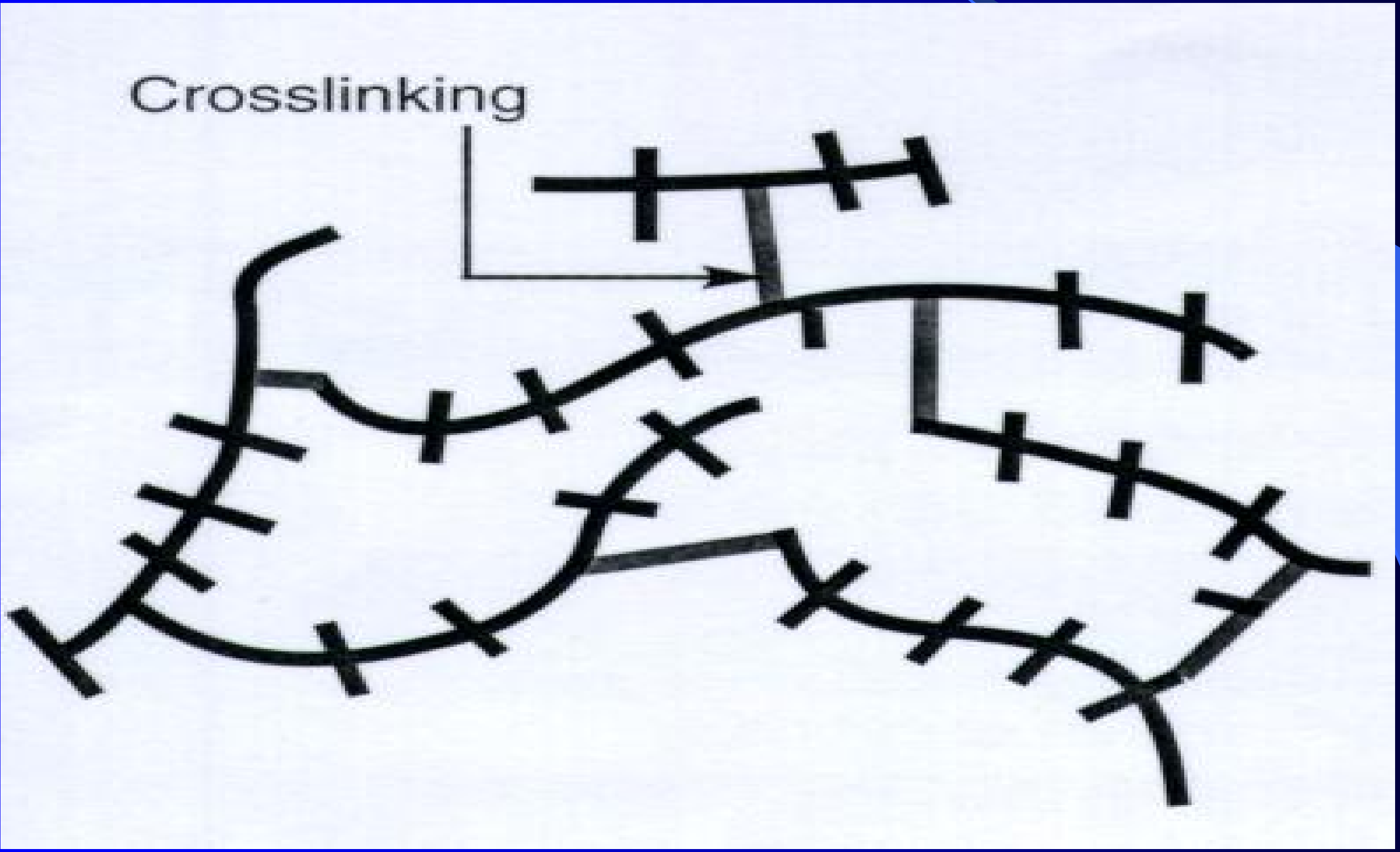
	Cobalt	Chromium	Nickel
Co-Cr-Co-Cr	43.1	57.2	2.3
Co-Cr-bone	0.7	3.4	4.0
Co-Cr-PE	0.56	0.86	0.31
Stainless Steel-PE	0.06	0.56	0.76

Cross-Linking

- **Definition:**

The bonding of adjacent molecular chains in a material creating a three-dimensional molecular structure that more efficiently resists sliding forces.

Cross-Linking (Cont)



Cross-Linking (Cont)

- Cross-Linked UHMWPE.
  - demonstrated impressive wear reduction.
  - it becomes more difficult for adhesive forces to separate molecules fro each other.
  - harder than noncross-linked.
  - extreme cross-linking leads to brittlness.

Cross-Linking (Cont)

- Since 1990 Improved UHMWPE
  - Elastic Modulus :

    from 800-1000 MPa   to 500-3000 MPa.
  - Yield Strength:

    from 18-25 MPa to 15-45 .

Thank You