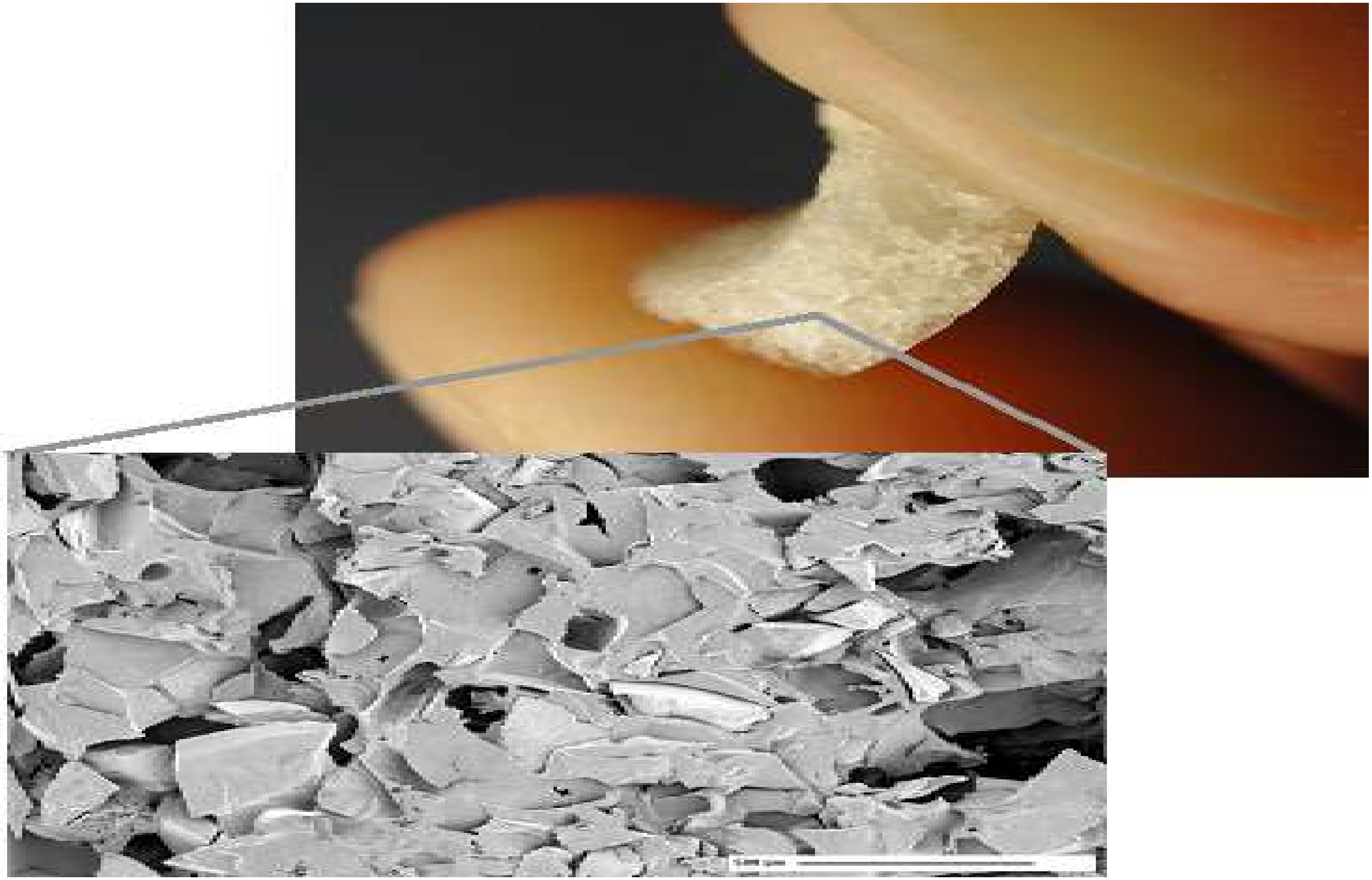
BIOMATERIALS & BIOCOMPATIBILITY



Source: http://polymeeri.tkk.fi/english/images/stories/research/bio_komposiitti.jpg

Properties of Materials

1 Mechanical properties

2 Electrical properties

3 Thermal properties

4 Chemical properties

5 Magnetic properties

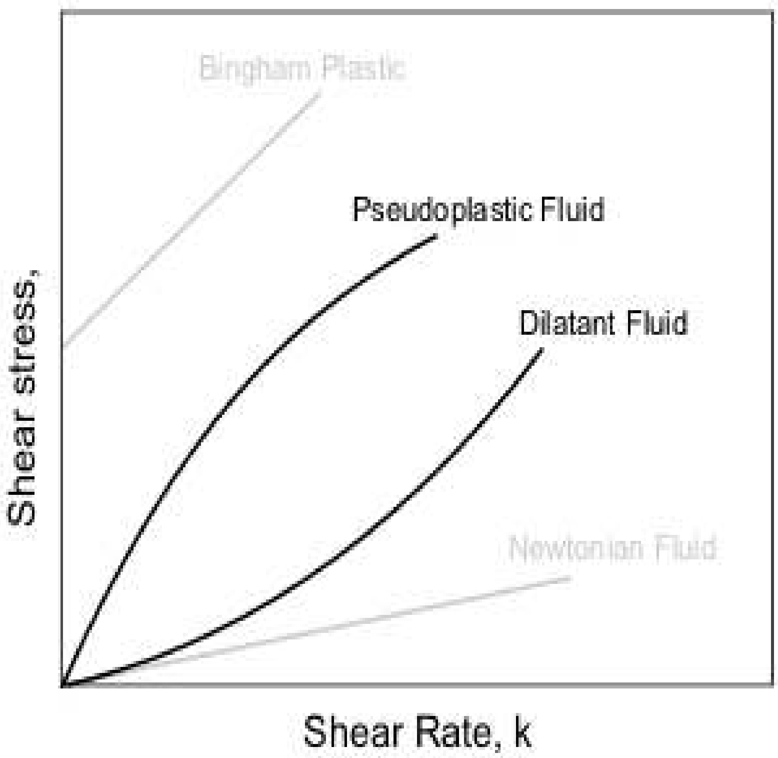
6 Optical properties

7 Acoustical properties

8 Radiological properties

9 Biological properties

Different types of responses (σ) to a change in strain rate (d /dt)



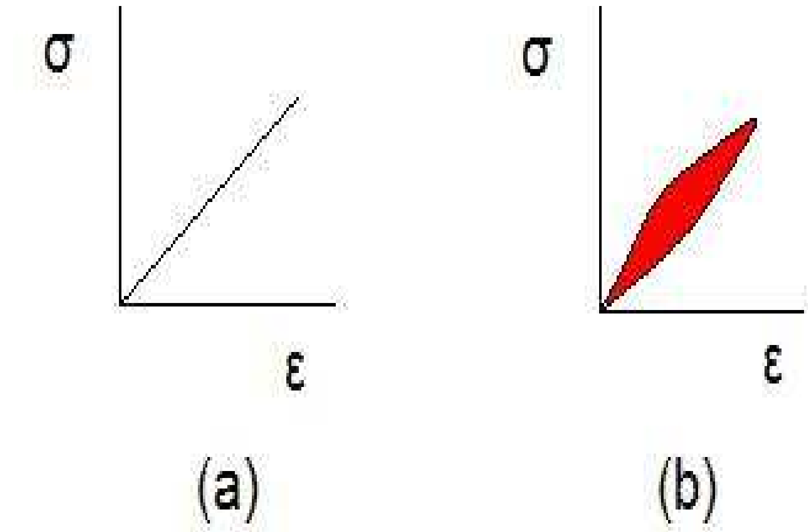
Source:://en.wikipedia.org/wiki/Viscoelasticity

- Viscoelasticity describes materials that exhibit both viscous and elastic characteristics when undergoing deformation.
- Viscous materials, like honey, resist shear flow and strain linearly with time when a stress is applied.
- Elastic materials strain instantaneously when stretched and just as quickly return to their original state once the stress is removed. Viscoelastic materials have elements of both of these properties and, as such, exhibit time dependent strain.

Hysteresis

- **Hysteresis** is a property of systems (usually physical systems) that do not instantly react to the forces applied to them, but react slowly, or do not return completely to their original state. The state of such a system depends on its immediate history.

- For example, if you push on a piece of putty it will assume a new shape, and when you remove your hand it will not return to its original shape, or at least not immediately and not entirely.



Stress-Strain Curves for a purely elastic material (a) and a viscoelastic material (b).

The red area is a hysteresis loop and shows the amount of energy lost (as heat) in a loading and unloading cycle. It is equal to $\oint \sigma \, d\varepsilon$ where σ is stress and is strain.

Elasticity

- A material is said to be **elastic** if it deforms under stress (e.g., external forces), but then returns to its original shape when the stress is removed. The amount of deformation is called the strain.

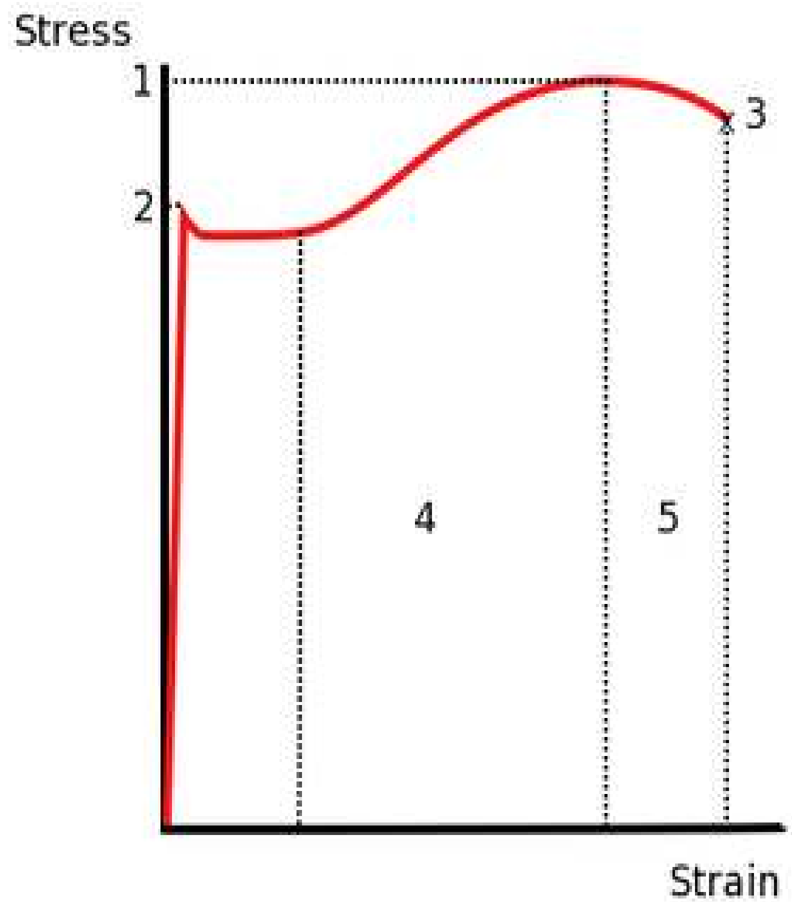
- **Hooke's law** of elasticity is an approximation that states that the amount by which a material body is deformed (the strain) is linearly related to the force causing the deformation (the stress).

- For systems that obey Hooke's law, the extension produced is directly proportional to the load:
  –
- where $\vec{F} = -k\vec{x}$
  – *x* is the distance by which the material is elongated [usually in meters],
  – *F* is the restoring force exerted by the material [usually in newtons], and
  – *k* is the **force constant** (or **spring constant**). The constant has units of force per unit length [usually in newtons per meter].

Stress-strain Curve

- Stress-strain curve for low-carbon steel. Hooke's law is only valid for the portion of the curve between the origin and the yield point.

  1. Ultimate strength
  2. Yield strength-corresponds to yield point.
  3. Rupture
  4. Strain hardening region
  5. Necking region.



BIOMATERIAL

"any substance (other than drugs) or combination of substances synthetic or natural in origin, which can be used for any period of time, as a whole or as a part of a system which treats, augments, or replaces any tissue, organ, or function of the body".

Biocompatibility — The ability of a material to perform with an appropriate host response in a specific application

Host Response — The response of the host organism (local and systemic) to the implanted material or device.

Biomaterials - History

- Romans, Chinese, and Aztecs used gold in dentistry over 2000 years ago, Cu not good.
- Ivory & wood teeth (George Washington owned wooden dentures)
- Aseptic surgery 1860 (Lister)
- Bone plates 1900, joints 1930
- Turn of the century, synthetic plastics came into use
  - Parachute cloth used for vascular prosthesis
- 1960- Polyethylene and stainless steel being used for hip implants

Acute Inflammation Components

Physiological Responses	Symptoms
Release of soluble mediators	Heat (calor)
Vasodilation	Redness (rubor)
Increased blood flow	Swelling (tumor)
Extravasation of fluid (permeability)	Pain (dolor)
Cellular influx (chemotaxis)	
Elevated cellular metabolism	

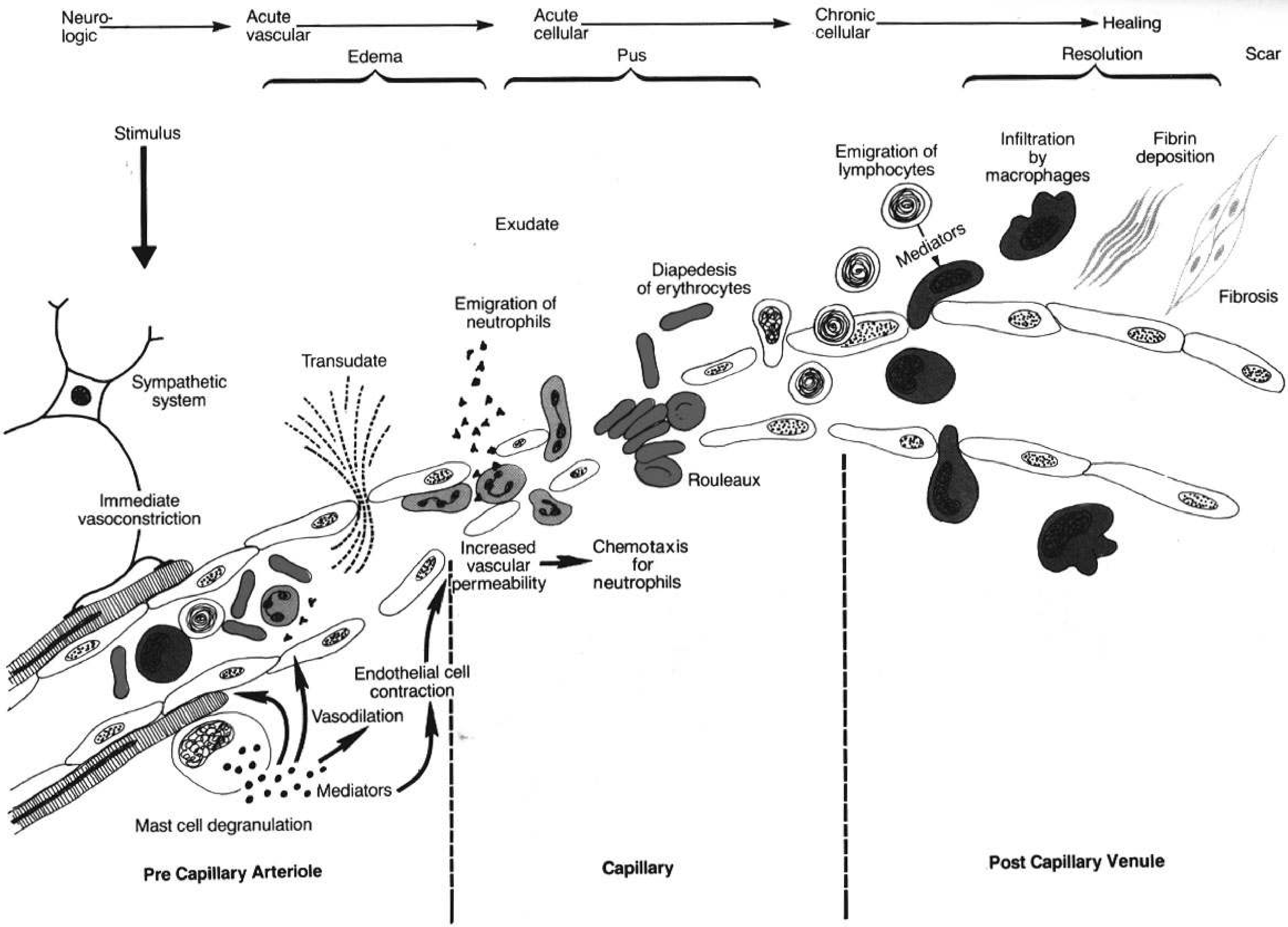
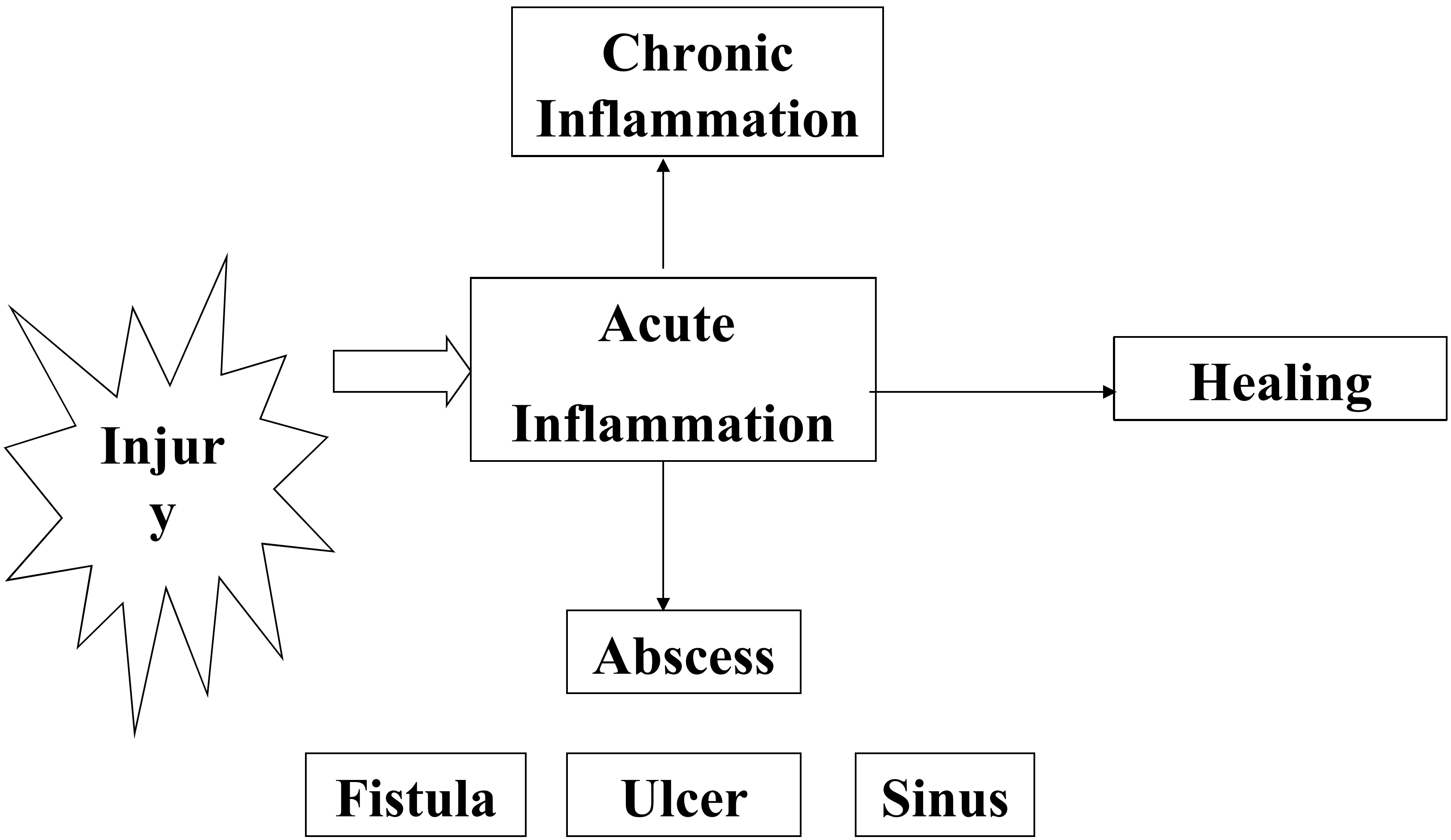


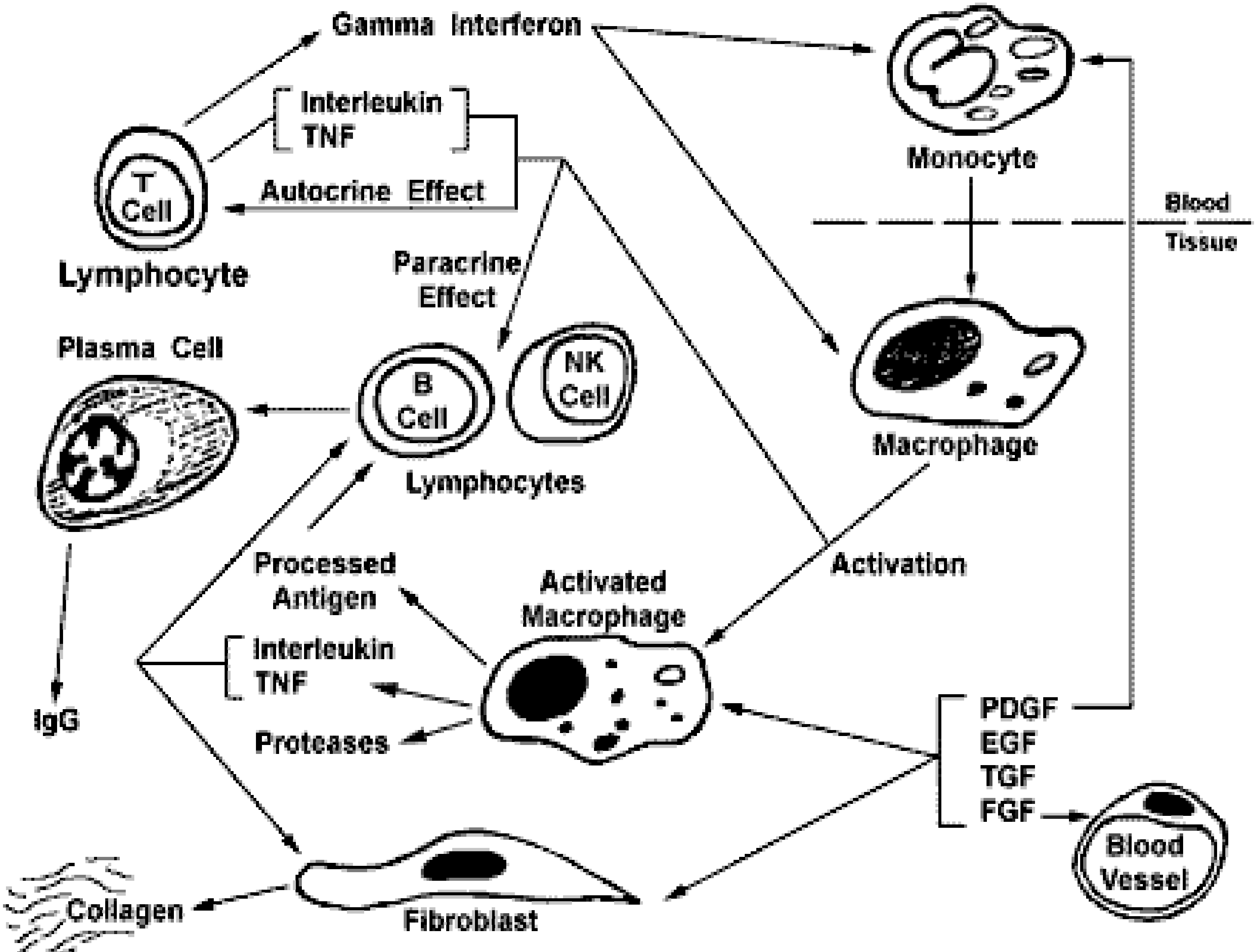
Figure 12-1. The sequence of events in the process of inflammation.

Inflammation end points



Modified from: www.eohsi.rutgers.edu/internal/classes/pathophysiology/Inflamlect2707

Chronic Inflammation



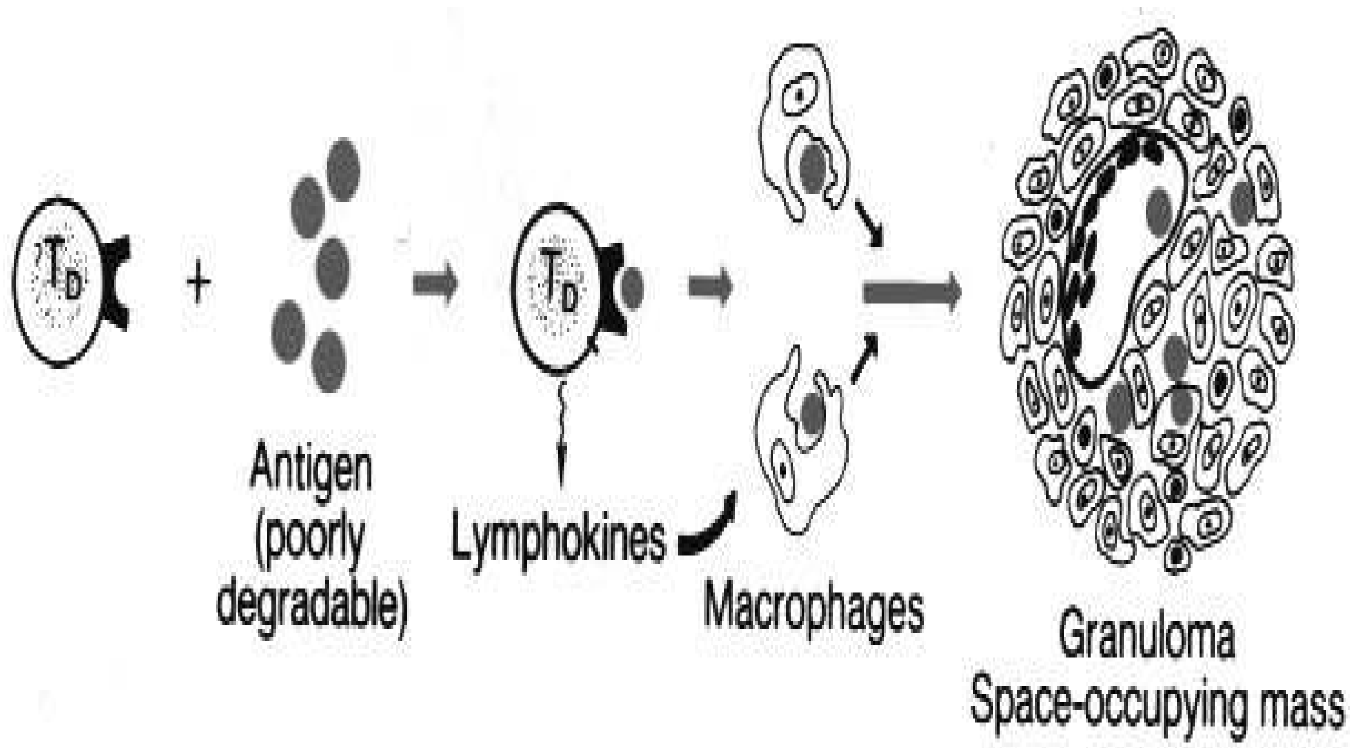
Source: www.eohsi.rutgers.edu/internal/classes/pathophysiology/Inflamlect2707

Acute Vs Chronic

- Flush, Flare & Weal
- Acute inflammatory cells - Neutrophils
- Vascular damage
- More exudation
- Little or no fibrosis

- Little signs - Fibrosis,
- Chronic inflammatory cells – Lymphocytes
- Neo-vascularisation
- No/less exudation
- Prominent fibrosis

Foreign Body Granuloma



GRANULOMA FORMATION – MASSING OF MACROPHAGES SURROUNDED BY LYMPHOCYTES, ASSOCIATED WITH FOREIGN BODIES

Modified from: www.eohsi.rutgers.edu/internal/classes/pathophysiology/Inflamlect2707

Evolution of Biomaterials

Structural

Soft Tissue Replacements

Functional Tissue Engineering Constructs

Polymeric Biomaterials

Advantages	vs	Disadvantages
Easy to make		Leachable
Tailorable properties		Absorb water & proteins
Surface modification		Surface contamination
Immobilize Cells		Wear & breakdown
Biodegradable		Biodegradation
		Difficult to sterilize

- PMMA, PVC, PLA/PGA, PE, PTFE, PET, Silicones

Ceramics

Advantages vs Disadvantages

High compression strength	Low strength in tension
Can be highly polished	Low fracture toughness
Wear & corrosion resistance	Mismatched with bone
Inert	Difficult to fabricate

Alumina, Zirconia, Silicate glass, Calcium phosphate, Calcium carbonate

Metals

Advantages	vs	Disadvantages
High strength		High modulus
Fatigue resistance		Corrosion
Wear resistance		Metal ion toxicity
Simple to fabricate		Metallic looks
Easy to sterilize		
Shape memory		

Stainless Steel (316L), Co-Cr alloys, Au-Ag-Cu-Pd alloys, Amalgam (AgSnCuZnHg)

Ni-Ti, Titanium

Biomaterials

Criteria for selection of materials

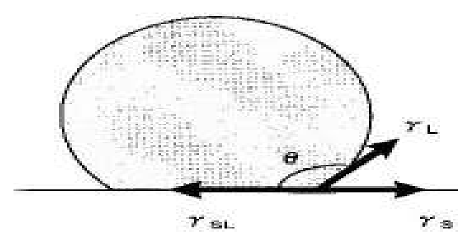
- Mechanical & chemical properties
- Acceptable cost/benefit ratio
- No undesirable biological effects, not cancer causing, toxic, allergenic or immunegic

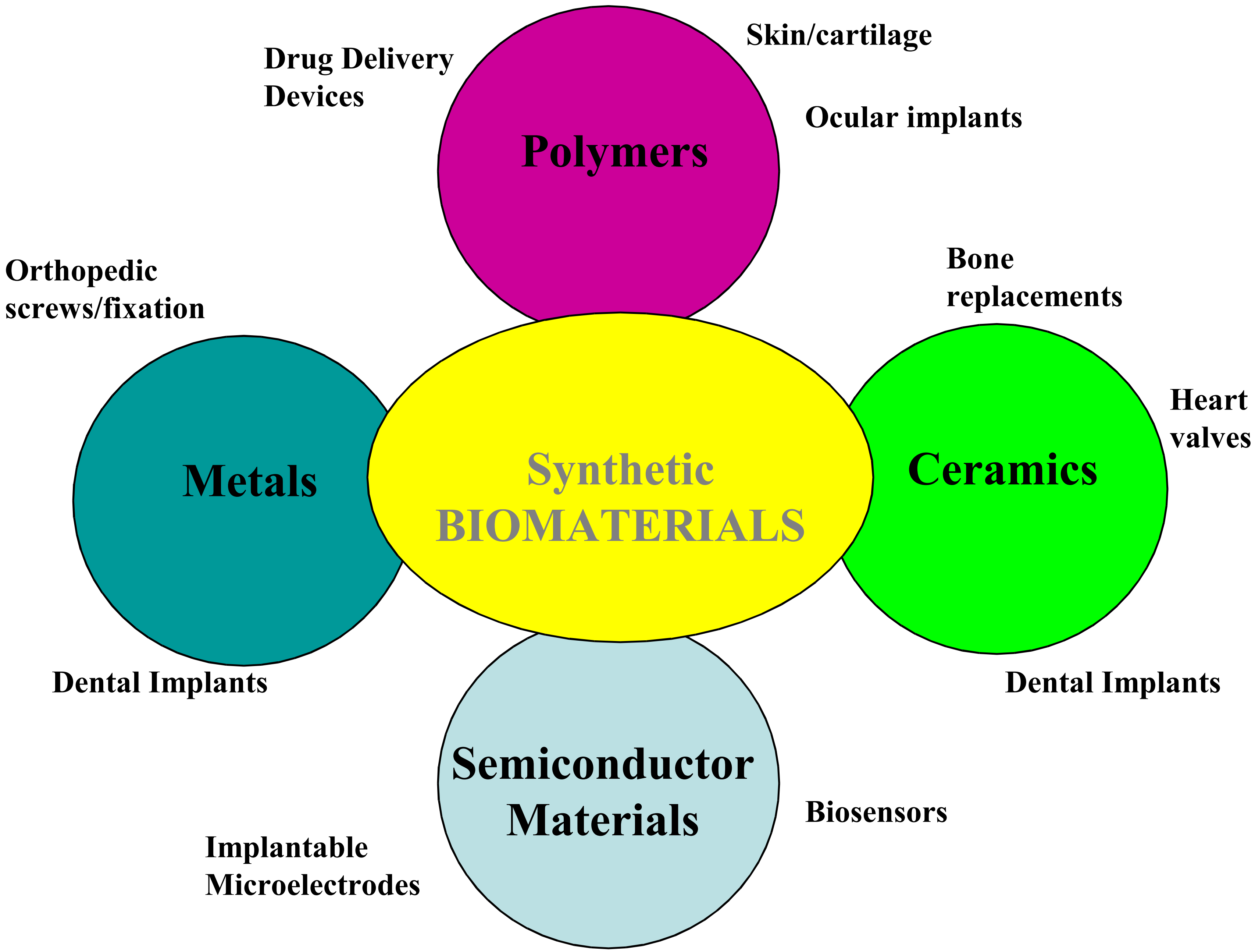
Deterioration by

- Corrossion
- Degradation
- Calcification
- Mechanical loading
- Combined

Surface Properties (surface roughness, energy, surface cleaniness measured by)

Contact angle
ESCA – surface chemical analysis
SEM

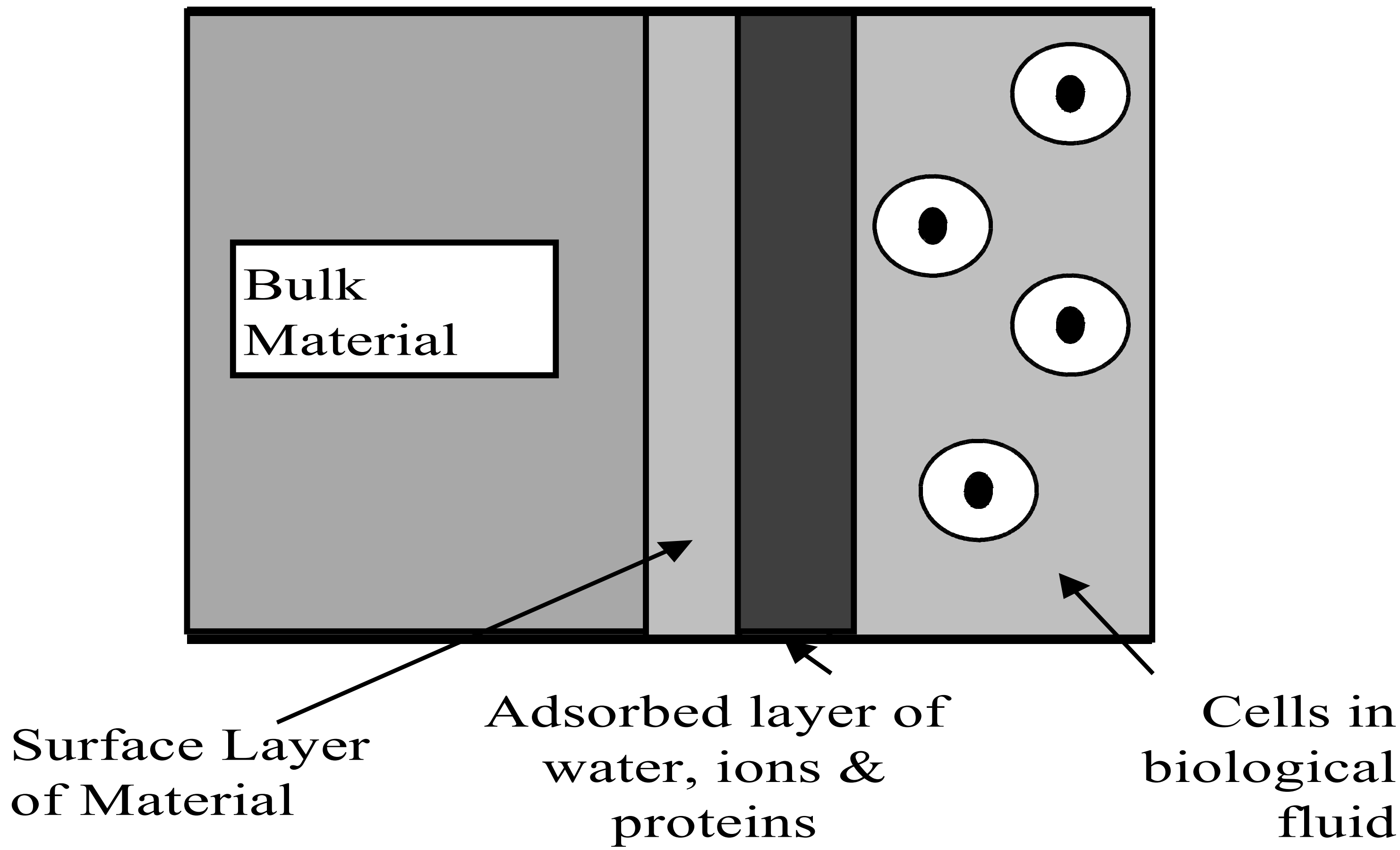



Drug Delivery
Devices
Polymers
Skin/cartilage
Ocular implants
Orthopedic
screws/fixation
Bone
replacements
Metals
Synthetic
BIOMATERIALS
Ceramics
Heart
valves
Dental Implants
Dental Implants
Semiconductor
Materials
Biosensors
Implantable
Microelectrodes

Biomaterials - Uses

- Replace diseased part – dialysis
- Assist in healing – sutures
- Improve function – contacts
- Correct function – spinal rods
- Correct cosmetic – nose, ear
- Replace rotten – amalgam
- Replace dead - skin

Biocompatibility is a surface phenomenon …



Test Animals

- Rabbits – ear, skin, pyrogen
- Horseshoe Crab – endotoxins
- Guinea Pigs – skin
- Mice – genotoxicity
- Pig – implant
- Bacteria - genotoxicity
- Test actual & elutants & extracts…
- People – long term

Cytotoxicity
Hemolysis
Complement Activation
PT/PTT Testing
Carcinogencity Testing

Rabbit Pyrogen
Implantation
Chronic Toxicity
Intracutaneous Reactivity
Irritation Testing
Histology

Examples

Material	Applications
Silicone rubber	Catheters, tubing
Dacron	Vascular grafts
Cellulose	Dialysis membranes
Poly(methyl methacrylate)	Intraocular lenses, bone cement
Polyurethanes	Catheters, pacemaker leads
Hydogels	Opthalmological devices, Drug Delivery
Stainless steel	Orthopedic devices, stents
Titanium	Orthopedic and dental devices
Alumina	Orthopedic and dental devices
Hydroxyapatite	Orthopedic and dental devices
Collagen (reprocessed)	Opthalmologic applications, wound dressings

First Generation Implants

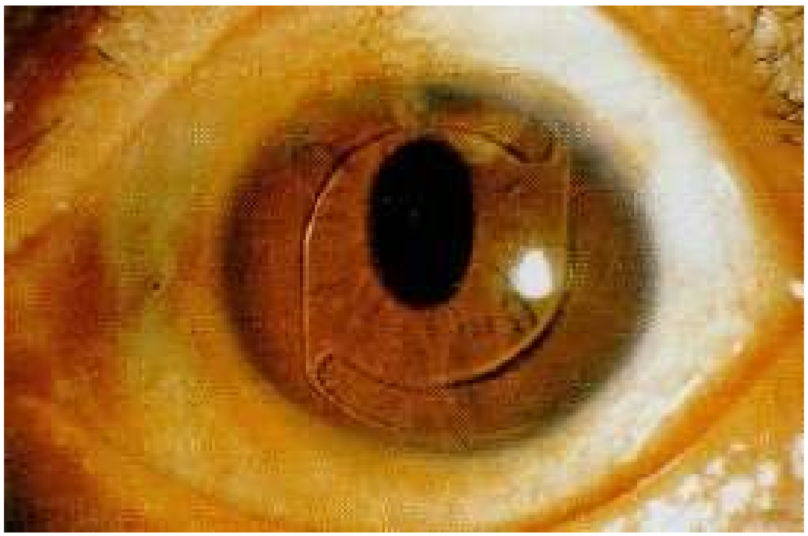
- “ad hoc” implants
- most successes were accidental rather than by design

Ex:

- gold fillings, wooden teeth, PMMA dental prosthesis
- steel, gold, ivory, etc., bone plates
- glass eyes and other body parts
- dacron and parachute cloth vascular implants

Intraocular Lens

3 basic materials - PMMA, acrylic, silicone



2^{nd} Generation implants

- engineered implants using common and borrowed materials
- developed through collaborations of physicians and engineers
- built on first generation experiences
- used advances in materials science (from other fields)

Ex:

- titanium alloy dental and orthopaedic implants
- cobalt-chromium-molybdinum orthopaedic implants
- UHMW polyethylene bearing surfaces for total joint replacements
- heart valves and pacemakers

Artificial Hip Joints

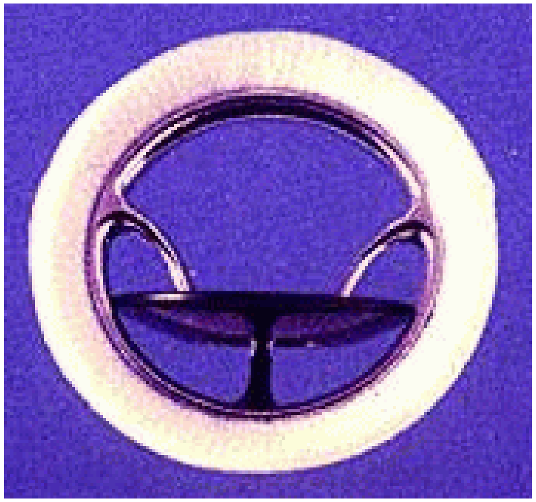
http://www.totaljoints.info/Hip.jpg

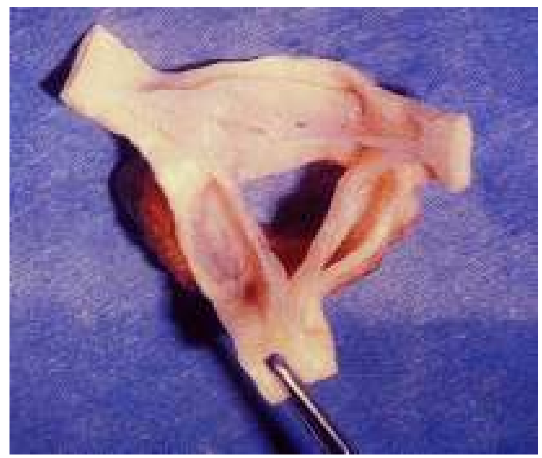
3rd generation implants

- bioengineered implants using bioengineered materials
- few examples on the market
- some modified and new polymeric devices
- many under development

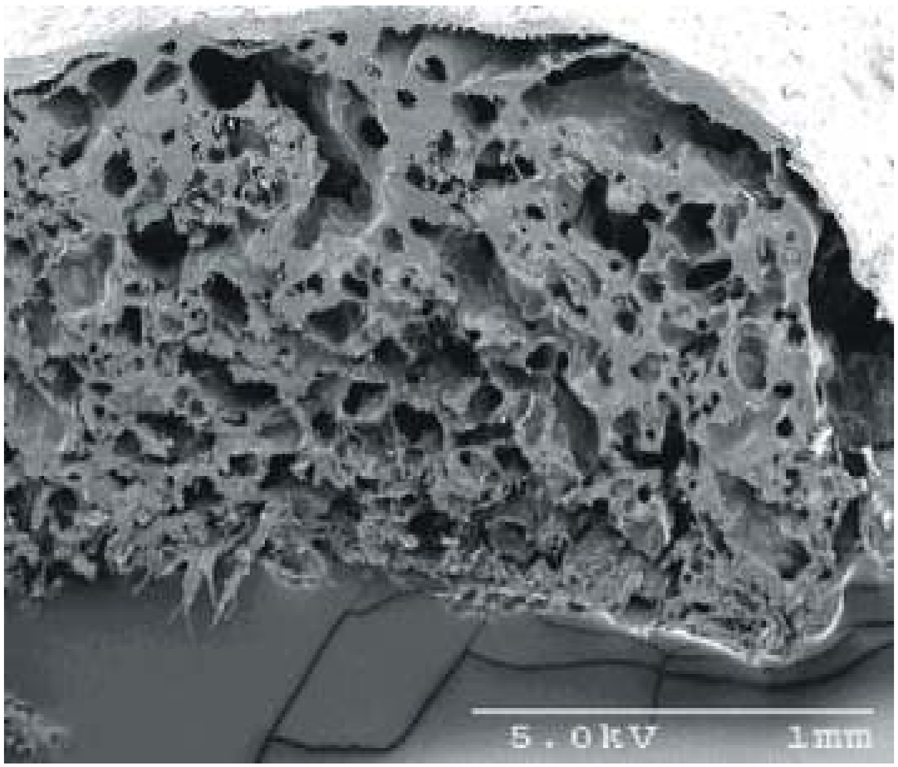
Ex:
•tissue engineered implants designed to regrow rather than replace tissues
•Integra LifeSciences artificial skin
•Genzyme cartilage cell procedure
•some resorbable bone repair cements
•genetically engineered “biological” components
(Genetics Institute and Creative Biomolecules BMPs)

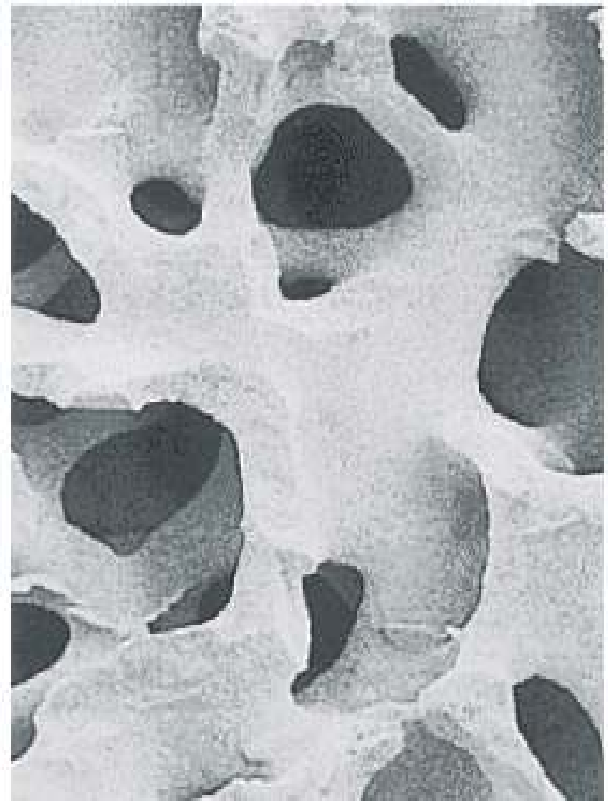
Substitute Heart Valves





SEM displaying the cross section of a composite disk, which had been seeded with cultured bone marrow stromal cells.





THANK YOU !