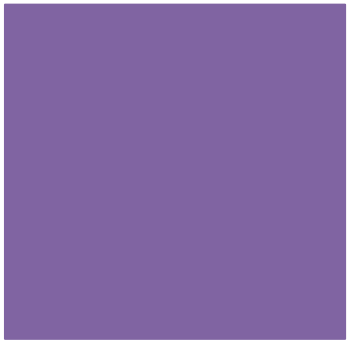

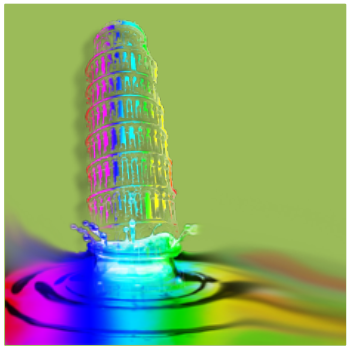

PRINCIPI BIOINGEGNERISTICI PER LO SVILUPPO DI SIMULATORI IN AMBITO MEDICO

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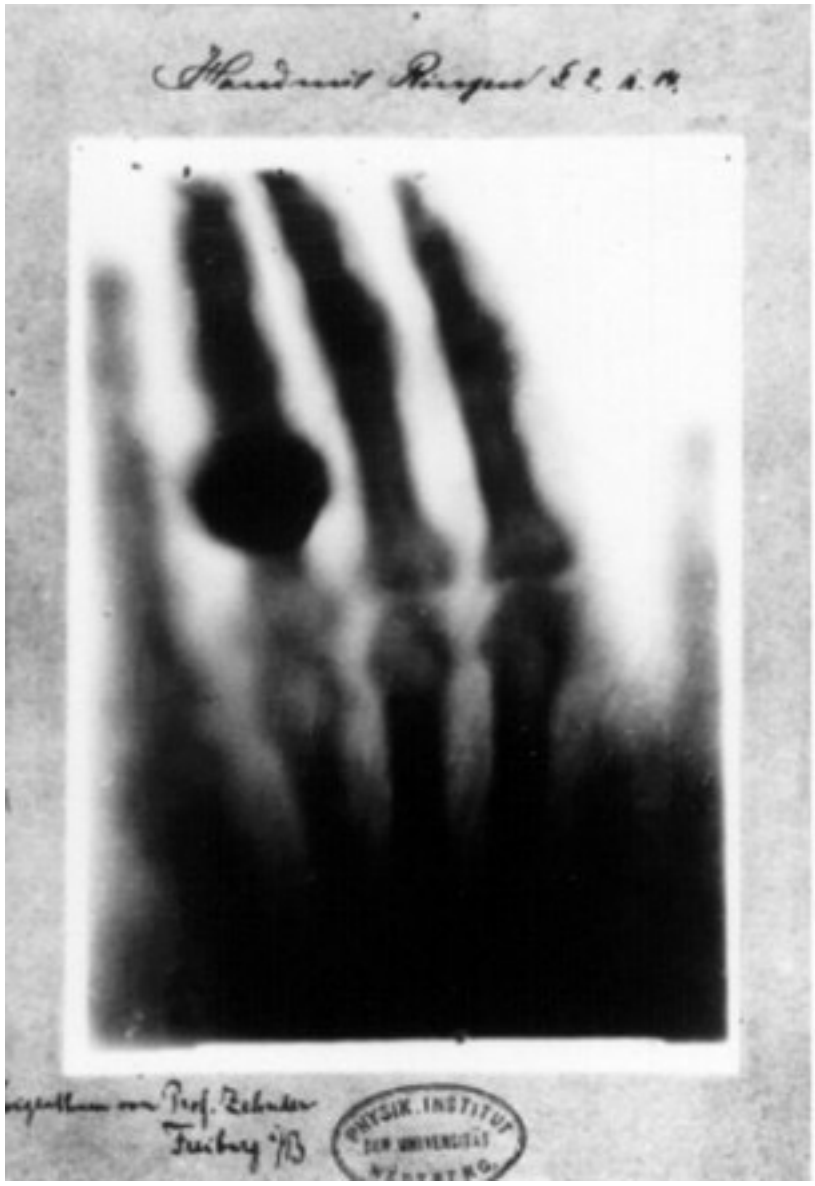
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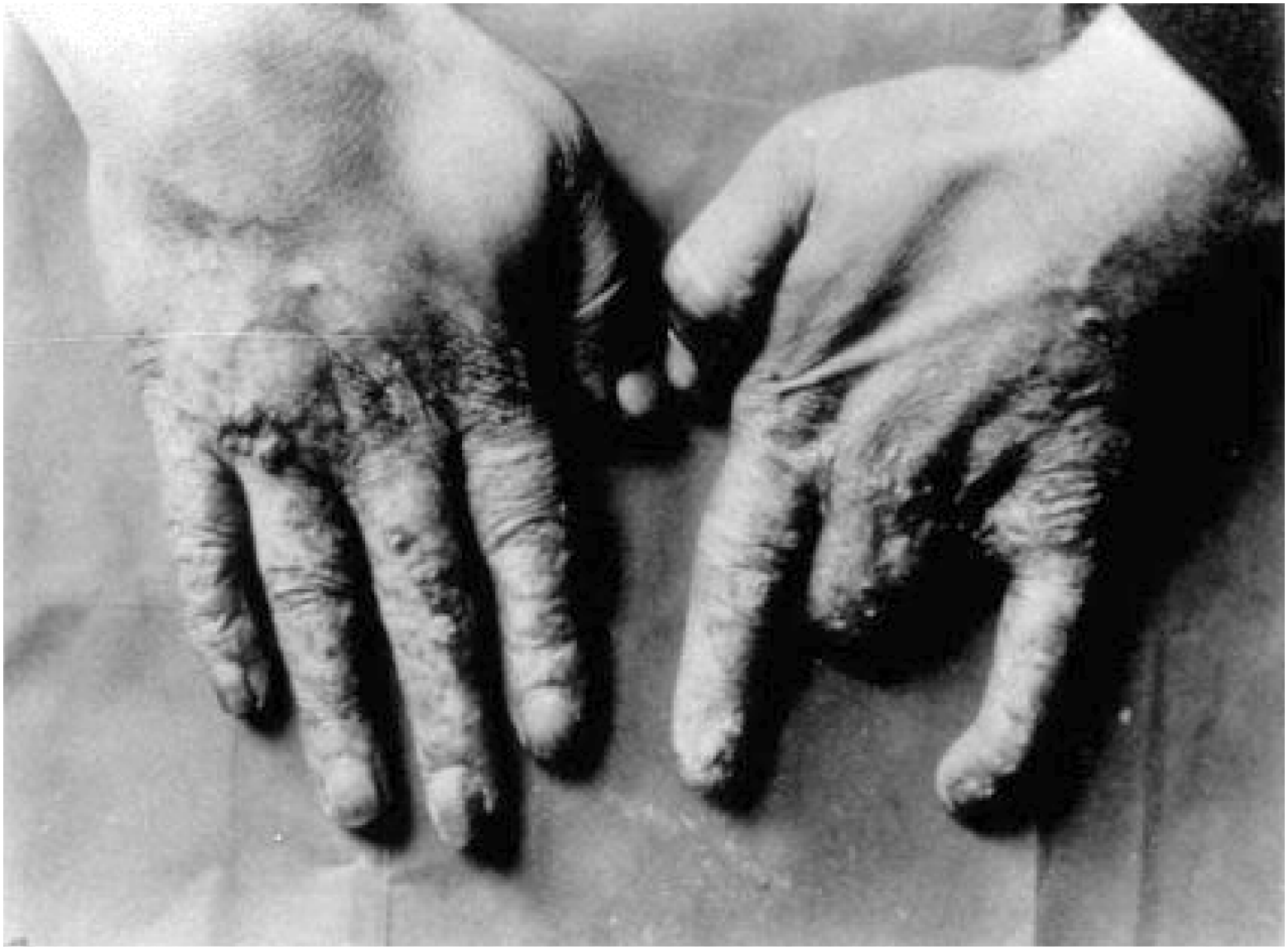
PHYSIK. INSTITUT



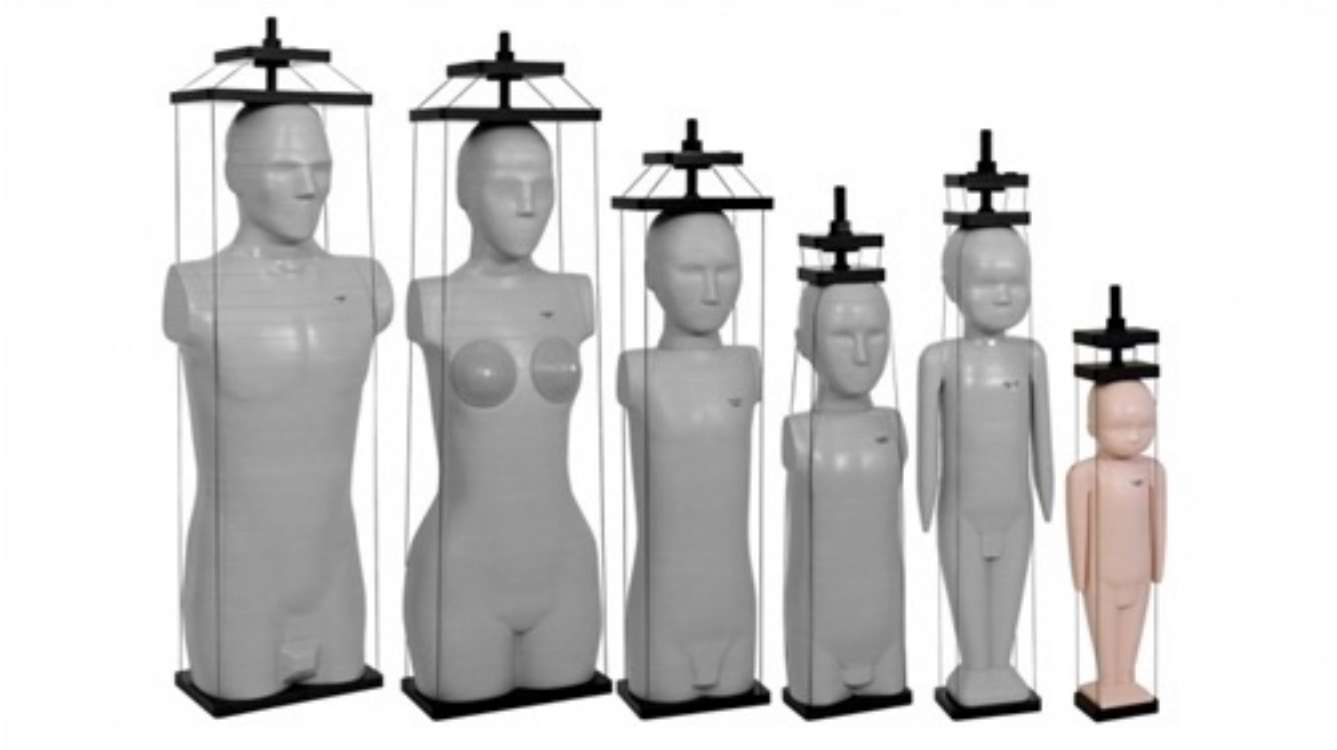
Phantom

oggetto fatto ad **imitazione della figura umana**, o di una sua parte, utilizzando **materiali non viventi** per simulare una sua particolare proprietà fisica e o chimica, per lo sviluppo, la verifica di sicurezza, la calibrazione, e la formazione all'uso di dispositivi, diagnostici, terapeutici o con altro scopo, che entrano in contatto con l'essere umano.

APPLICAZIONI

Applicazioni

- Banco di prova per una tecnologia
  - Ripetitività (stesse condizioni, breve periodo)
  - Riproducibilità



Applicazioni

- Formazione in chirurgia
  - no problemi etici,
  - sicurezza del paziente,
  - la gestione delle sale operatorie
  - la gestione del training

CLASSIFICAZIONE

Classificazione 1

Anatomia

- Distretto anatomico di interesse
  - Tessuto, organo o parte del corpo

Classificazione 2

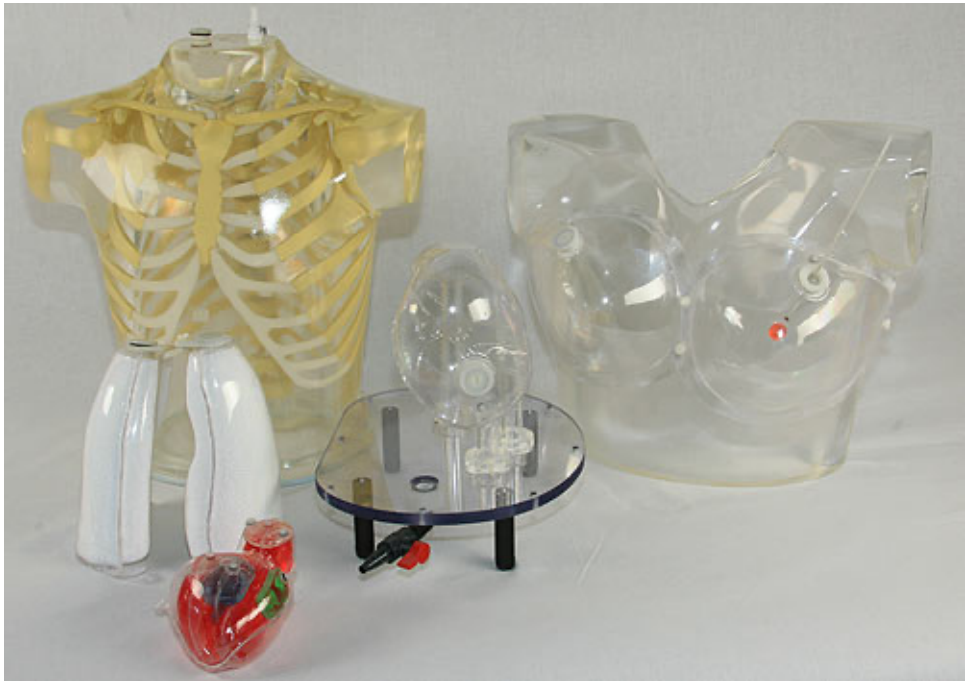
Geometria

- Phantom **non-antropomorfi**:
  - Riproducono solo le proprietà fisiche e chimiche del tessuto di interesse, e le sue dimensioni di massima
- Phantom **antropomorfi**:
  - riproducono sia le proprietà che la forma di organi e tessuti.

Classificazione 2

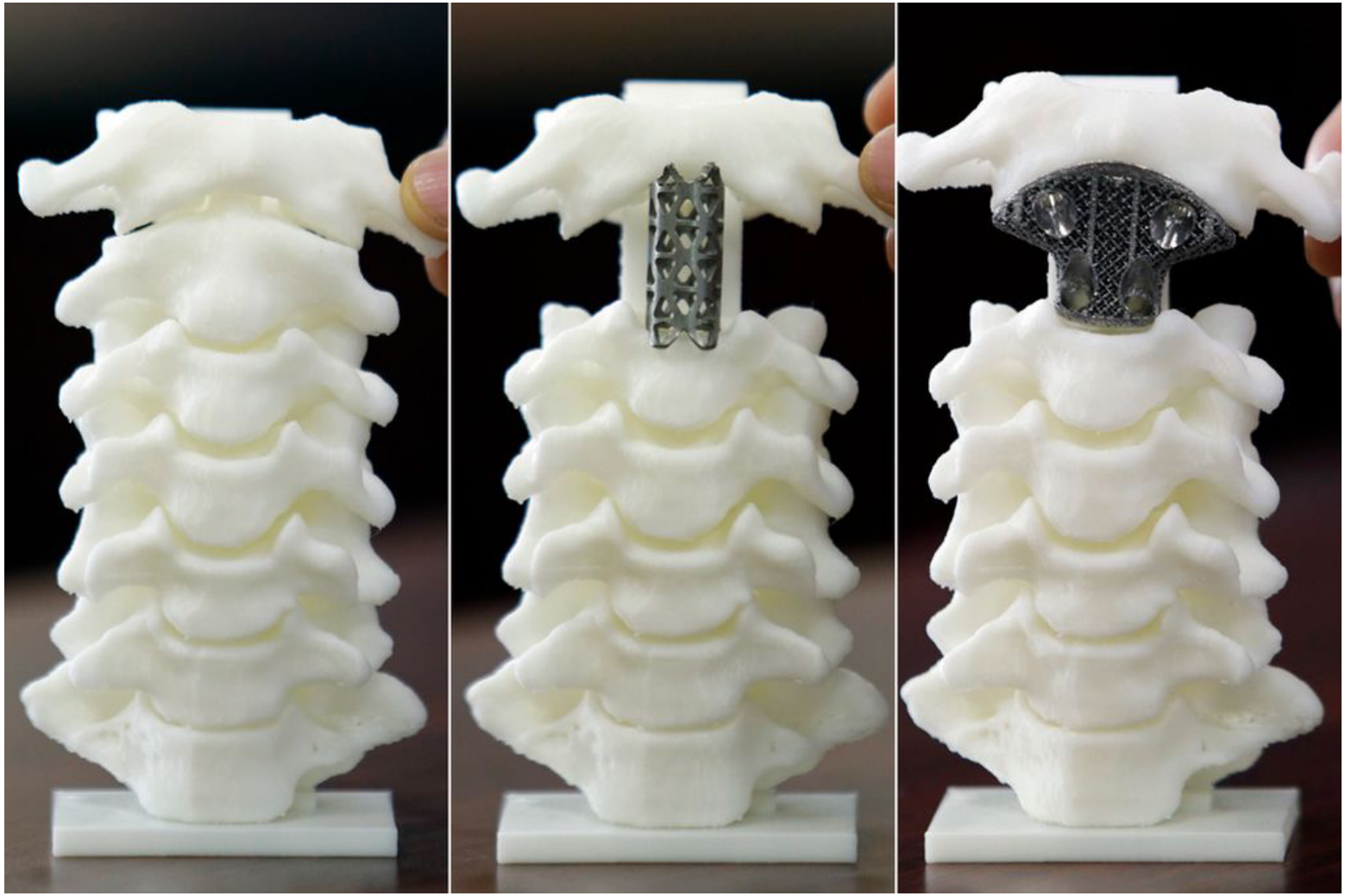
Geometria

Standard Grade Solid Water, Gammex 457



Classificazione 2

Geometria – 3D printed Phantom



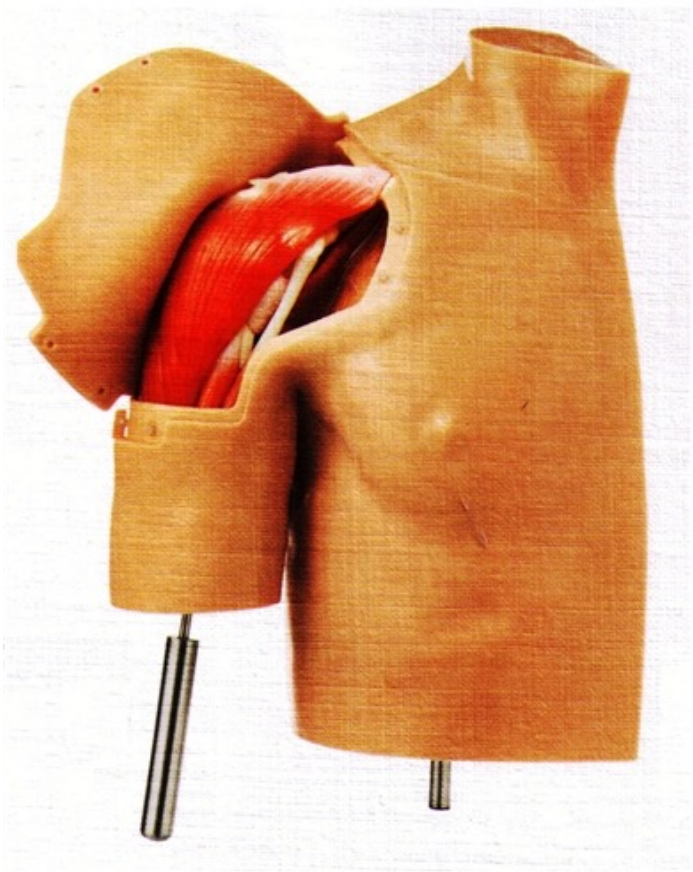
Classificazione 3

Stato fisico

- Phantom **fisici**,
  - modelli del corpo umano su cui effettuare test e misure utilizzando direttamente la strumentazione medica.
- Phantom **virtuali** (**o in silico**),
  - modelli al computer del corpo umano, su cui è possibile agire attraverso le periferiche del computer stesso.

Phantom Fisici

- Suddivisibile sulla base dello stato dei materiali utilizzati in:
  - Phantom solidi
  - Phantom liquidi



Phantom virtuali

- Suddivisibile in:
  - Phantom interattivi
  - Phantom per il calcolo
    - probabilistici,
    - deterministici

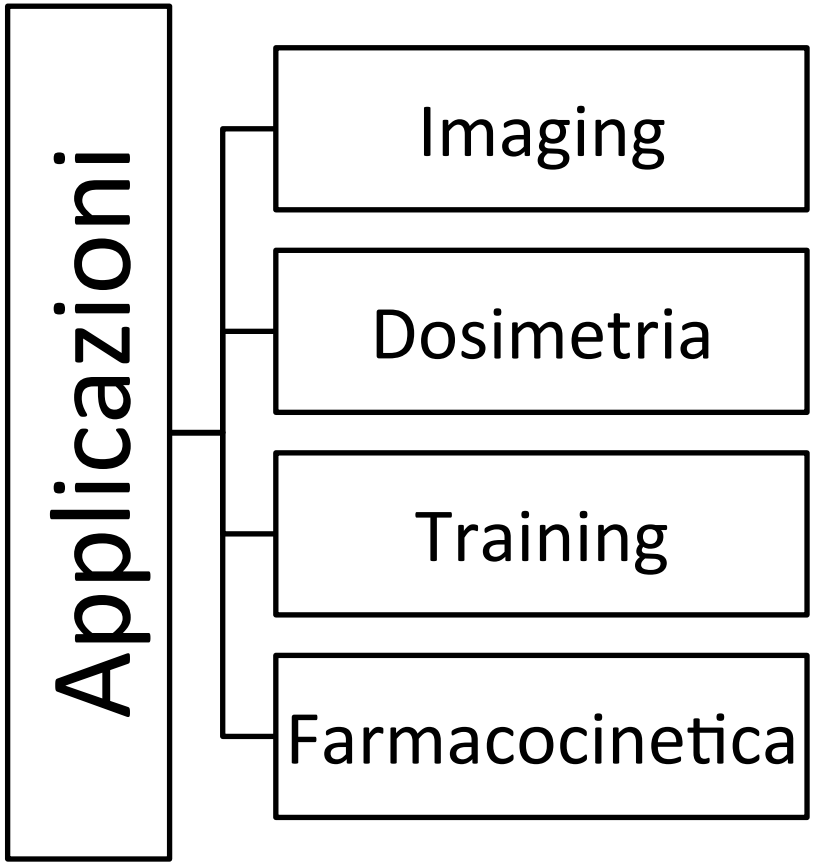
Classificazione 2+3

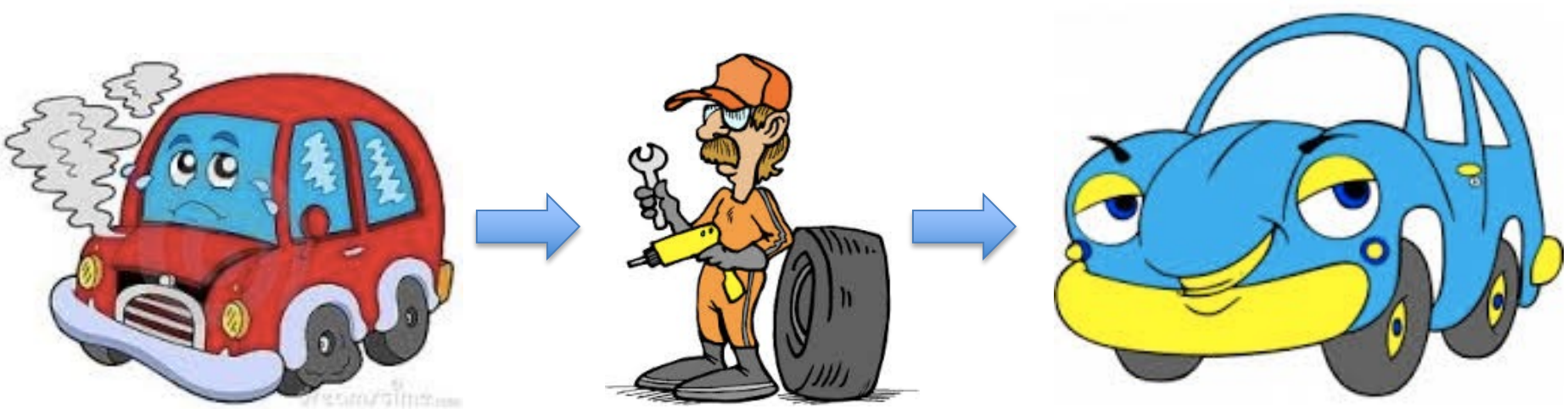
Caratteristiche costruttive

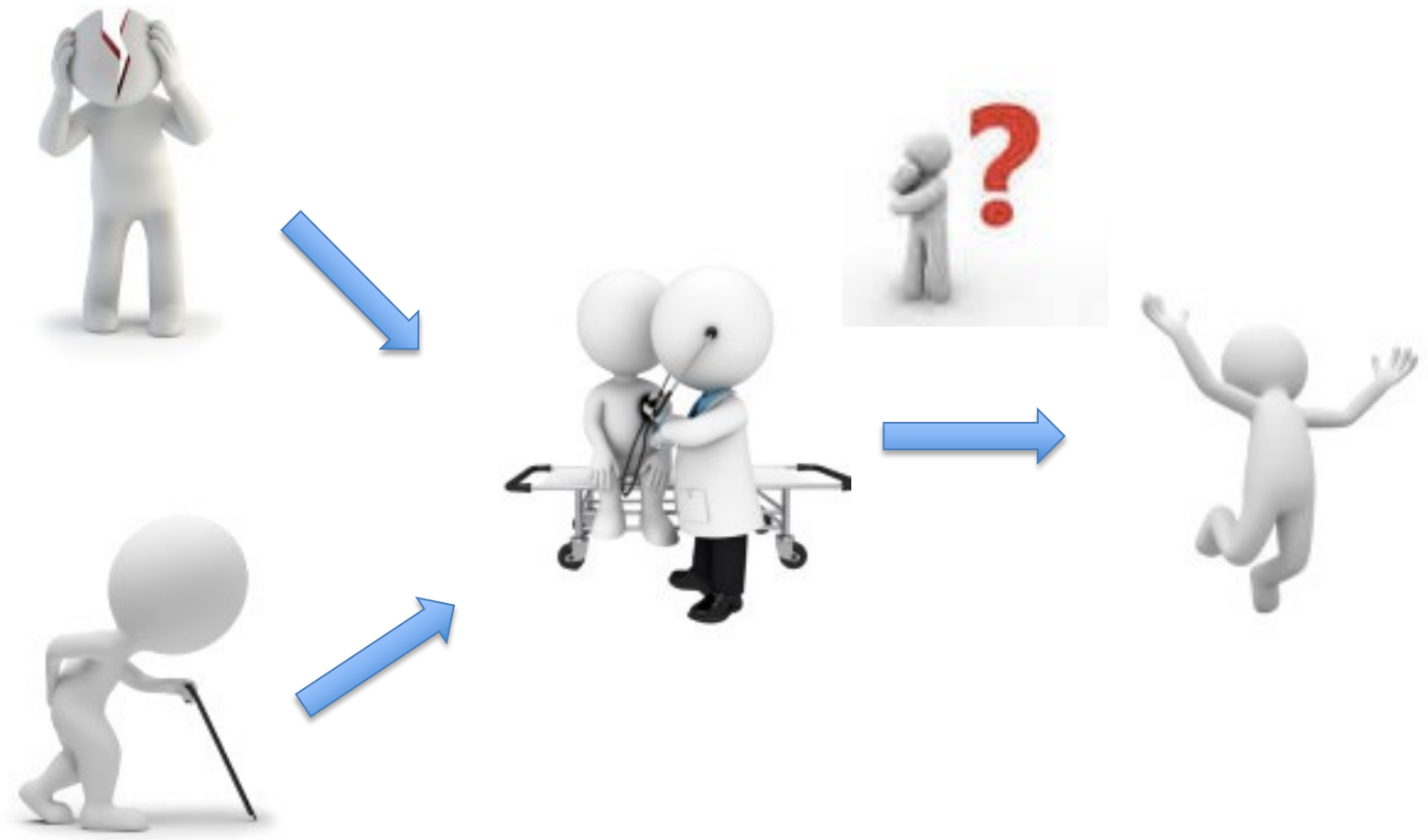
	Non-antropomorfi	Antropomorfi
Fisici	Cilindri per misure dosimetriche	Manichini per cateterizzazione e per la chirurgia laparoscopica
Virtuali	Modelli a geometria sferica, usati per validare la soluzione numerica con una soluzione analitica	Simulatori di chirurgia computer assistita

Classificazione 4

Applicazioni

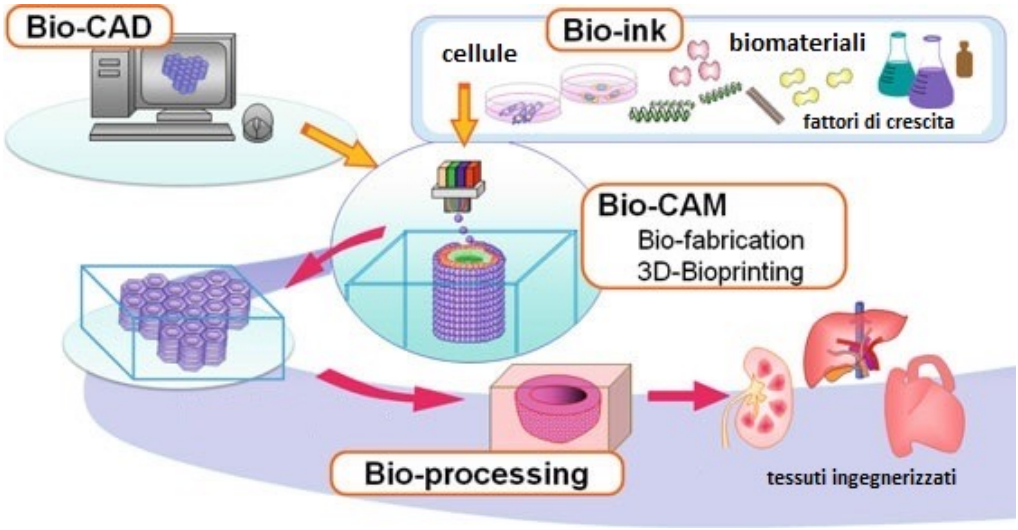


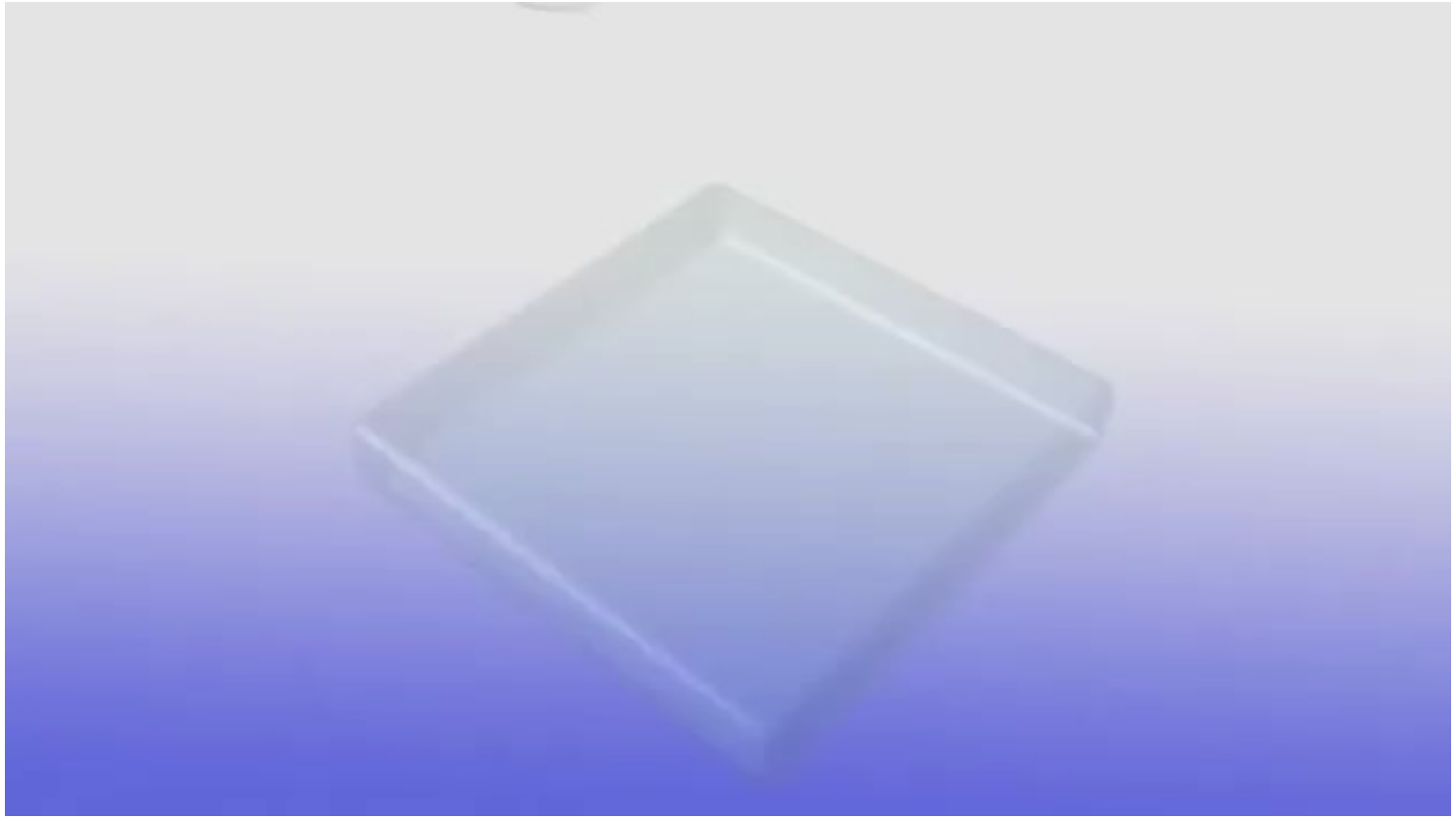




Bio-fabbricazione

Uso di processi computerizzati e tecnologie di stampa per la rigenerazione dei tessuti umani

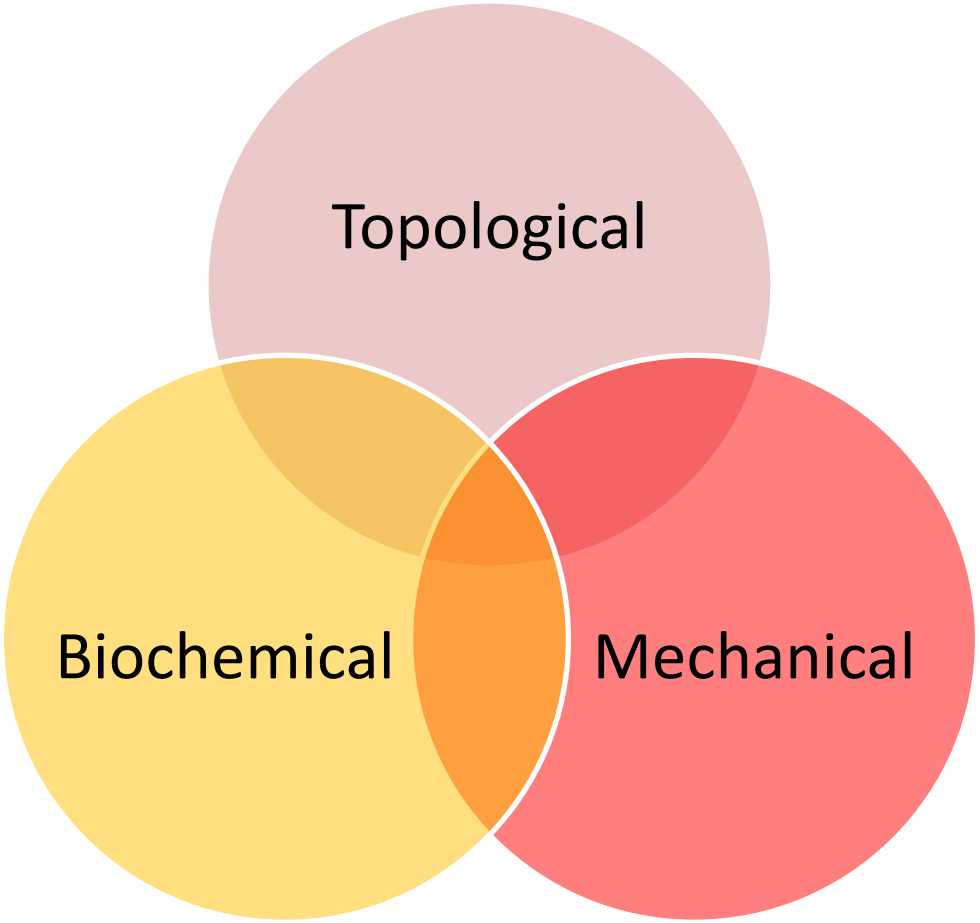





EPSON

How we may mimic natural tissue?

Three main simuli



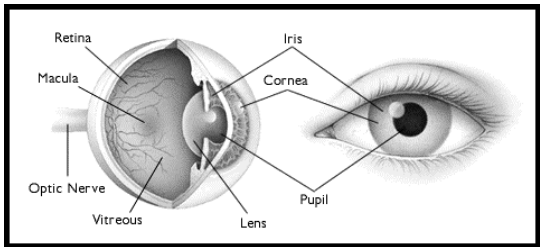
What are the main features of an ideal scaffold?

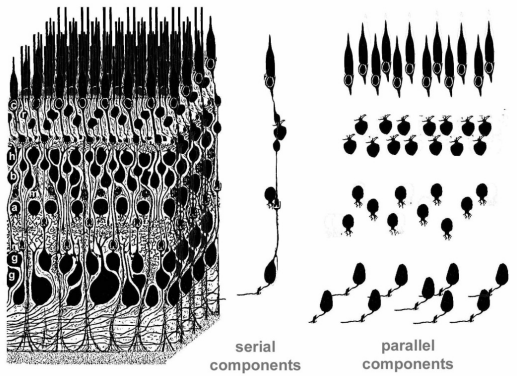
- Biocompatible, bioerodable and bioactive
- Well-defined topology
- Mechanical properties similar to those of natural tissue
- Optimal micro- and nano-porosity

Structure

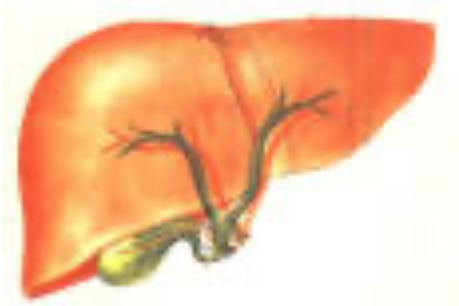
Function

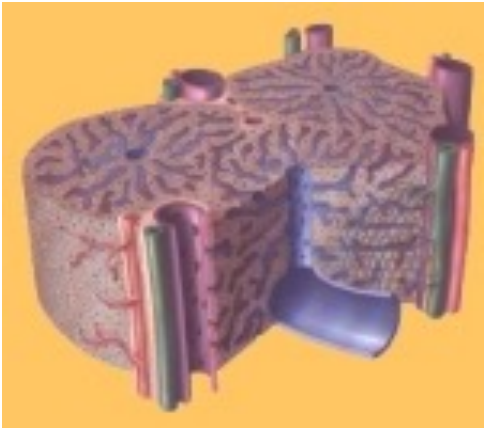
Retina



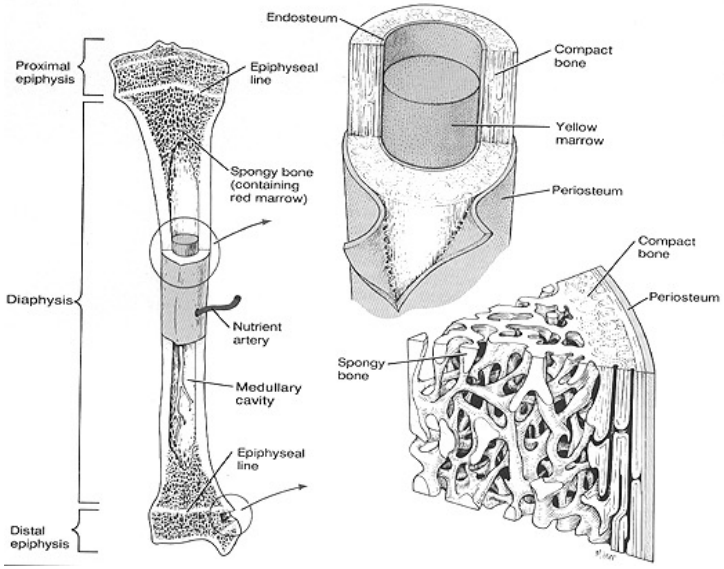


Liver





Bone

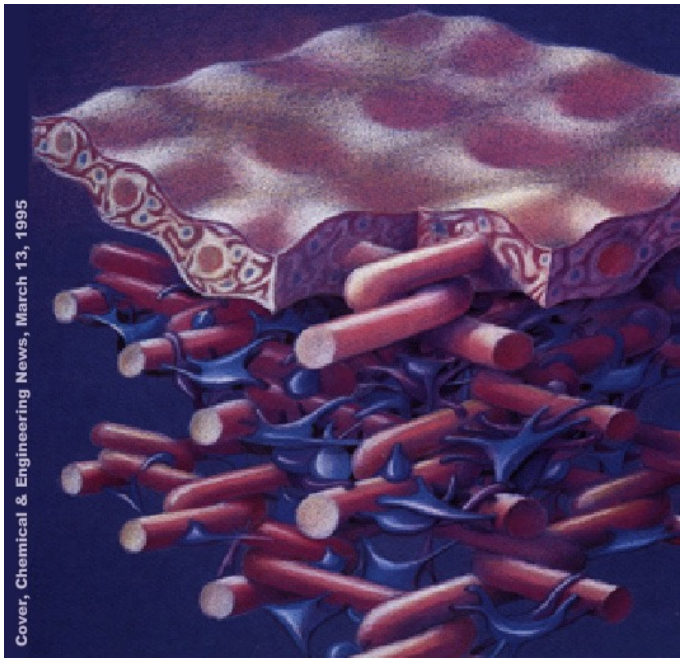


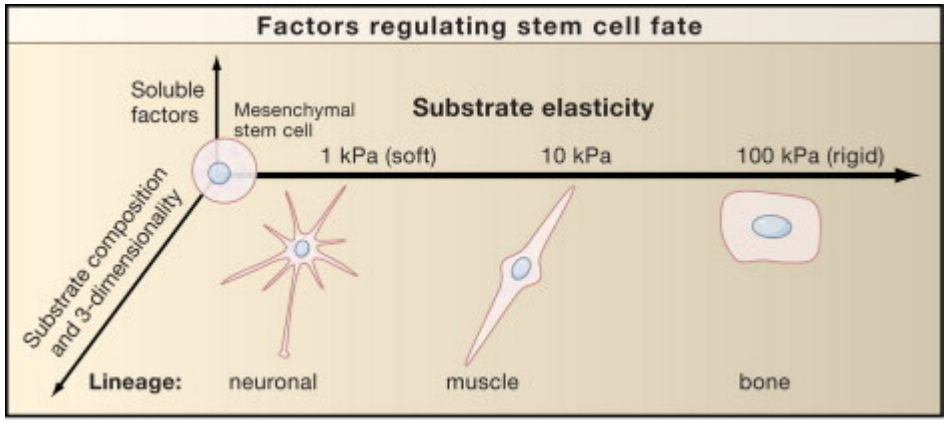
Biochemical stimulus

Synthetic biomaterials

Natural biomaterials

Decellelularized Tissue



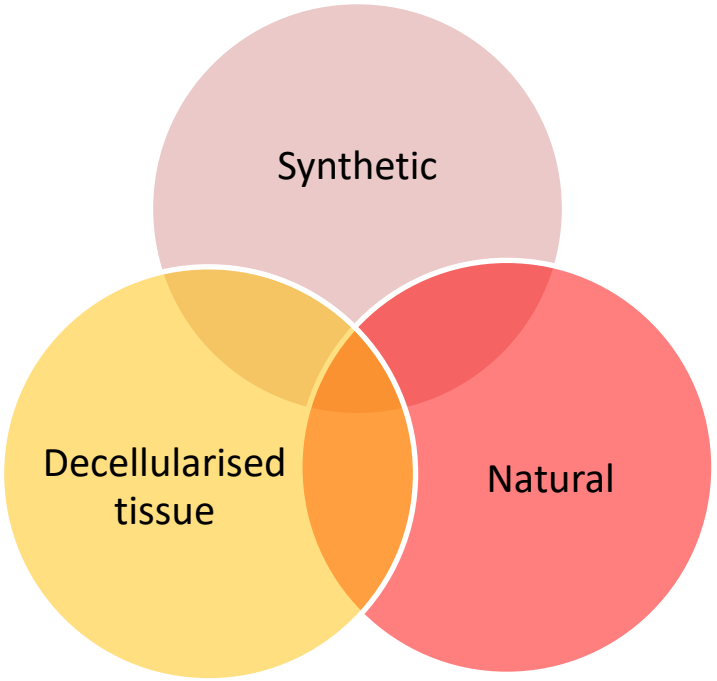


Even-Ram s et al, Matrix Control of Stem Cell Fate, Cell. Volume 126, Issue 4, 25 August 2006, Pages 645–647

Biochemical stimulus
Pro & contra

Biomaterial	Reproducibility	Processability	Biochemical feature	Mechanical feature
Synthetic	√	√	X	X
Natural	X	X	√	√
Decellelularized	X	X	√	√

Biohydrid and bioactive materials



- to have matricellular cues
- to be able to scavenge and deliver morphogenic factors
- to tune their mechanical properties during tissue regeneration process

Extracellular matrix features

- High degree of porosity
- High surface to volume ratio
- High degree of pore interconnection
- Appropriate pore size and geometry control
- Biochemical factors able to guide cell function activation

We need a bottom–up approach

A biomaterial is a material designed to interfere with biological materials to evaluate, treat, augment or replace any body tissue, organ or function (Chester 1991)

other properties

- Biocompatible
- Bioadsorbable, bioerodible, bioresorbable

Biocompatibility

Ability of a material, device or system to perform its function, without a significant clinical response of the host, within a specific application.

Hemocompatibility

It is essentially described by the following phenomena:

1- platelet adhesion (evaluated, for example, by platelet counts)

2- activation of the coagulation system (evaluated for example by determining the Thrombin/AntiThrombin complex)

3- activation of the complement system (evaluated eg by measuring the ratio C3a / C5a)

Classification

- Biopolymers: - synthetic
  - natural
- Metals
- Ceramics
- Composites

Synthetic Biomaterials

- Polymerisation process

- polyaddition (chain reaction), when the monomer has double or triple bonds between carbon atoms

- polycondensation (steps reaction) it is composed bry three phase

- Initial phase

$$R^{\bullet} + M \rightarrow RM^{\bullet}$$

- Growing phase

$$RM_{n+1}M^{\bullet} + R^{\bullet} \rightarrow RM_{n+1}R$$

$$RM_{n+1}M^{\bullet} + RH \rightarrow RM_{n+1}H + R^{\bullet}$$

$$RM_{n+1}M^{\bullet} + RM_{m}M^{\bullet} \rightarrow RM_{n+1} + RM$$

- End phase

$$RM^{\bullet} + M \rightarrow RMM^{\bullet}$$

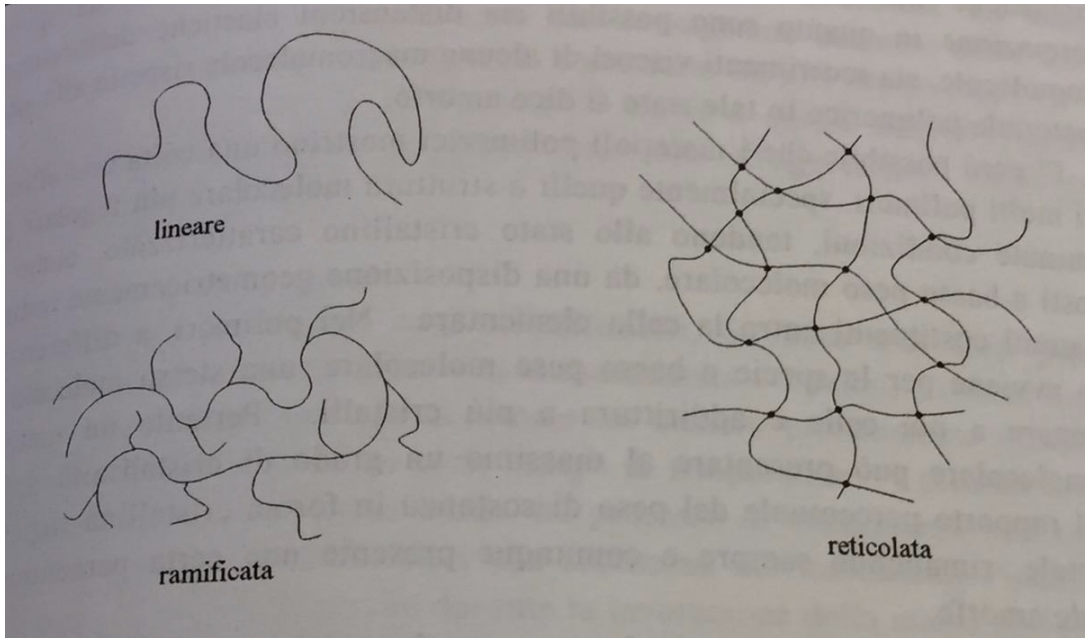
$$RMM^{\bullet} + nM \rightarrow RM_{n+1}M^{\bullet}$$

In polyaddition reaction there are no different reaction products from the initial molecules and the final polymers

In polycondensation reaction there are other reaction products such as water, NaCl, methanol, HCl, etc.

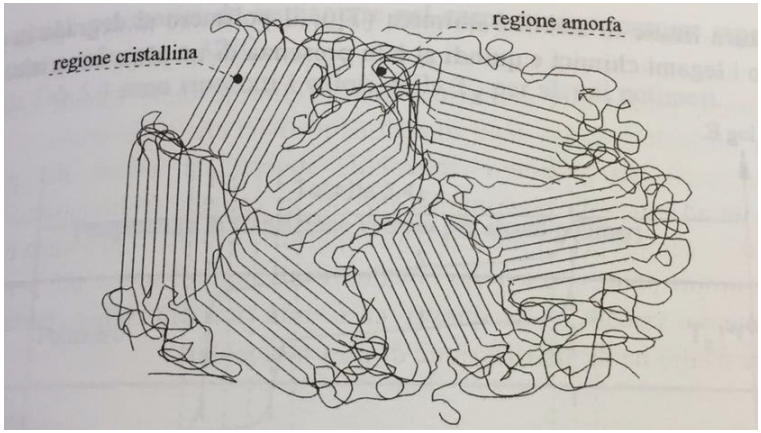
Features of synthetic polymers

- Molecular weight
- Chain structure

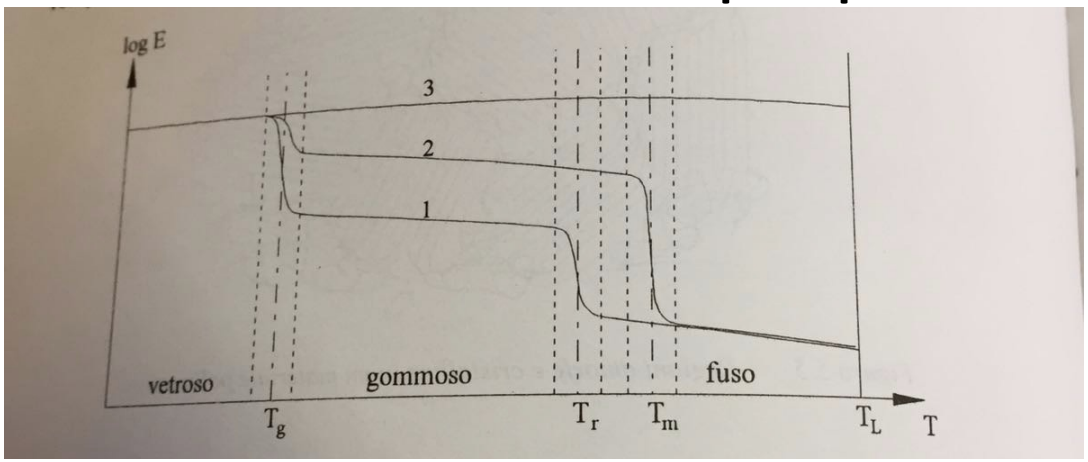


Features of synthetic polymers

- Cristallinity



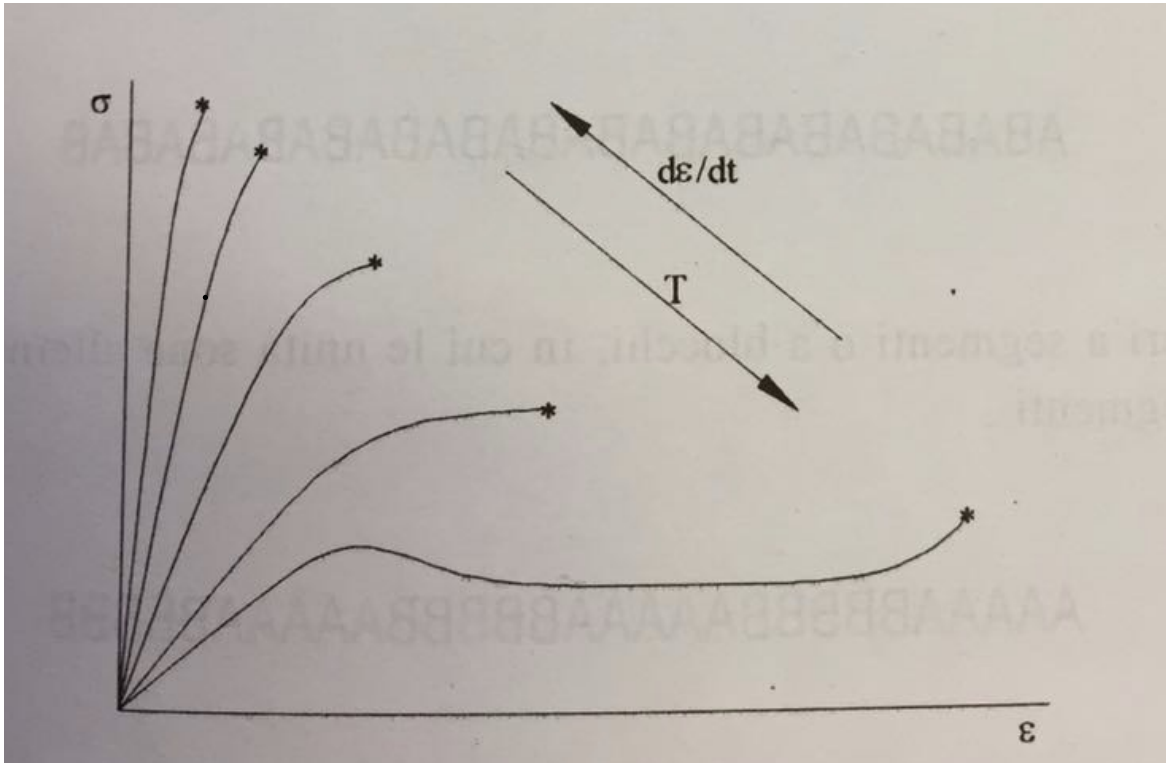
- Different thermal properties



Polimero	T_g [°C]
polietilene	-130
politetrafluoretilene	-122
polidimetilsilossano (gomma siliconica)	-120
gomma naturale	-70
poliuretano	-50 ÷ -20
polipropilene	-10
polivinilacetato	20 ÷ 30
poliammide 6.6 (Nylon)	50 ÷ 57
polietilentereftalato	69 ÷ 74
polivinilcloruro	78 ÷ 81
poliossimetilene	85
polistirene	82 ÷ 100
polimetilmetacrilato	100 ÷ 125
policarbonato	150

Features of synthetic polymers

- Different mechanical properties



Principal classes of synthetic biomaterials

- (1) Biodegradable linear aliphatic polyesters (e.g., polyglycolide, polylactide, polycaprolactone, polyhydroxybutyrate) and their copolymers
- (2) Biodegradable copolymers between linear aliphatic polyesters in (1) and monomers other than linear aliphatic polyesters like, poly(glycolide-trimethylene carbonate) copolymer, poly(L-lactic acid-L-lysine) copolymer, polycarbonates,etc;
- (3) Polyanhydrides;
- (4) Poly(orthoesters);
- (5) Poly(ester-ethers) like poly-p-dioxanone;
- (6) Biodegradable polysaccharides like hyaluronic acid, chitin and chitson;
- (7) polyamino acids like poly-L- glutamic acid and poly-L-lysine;
- (8) Inorganic biodegradable polymers like polyphosphazene.

Degradation

Principal role in the degradation is due to free radicals, that induce change in the PH and in the binding forces between the different monomers

Natural biopolymers

- Collagen

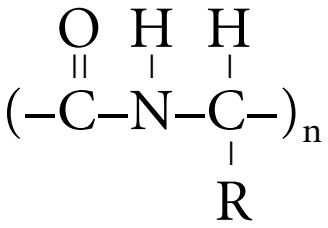
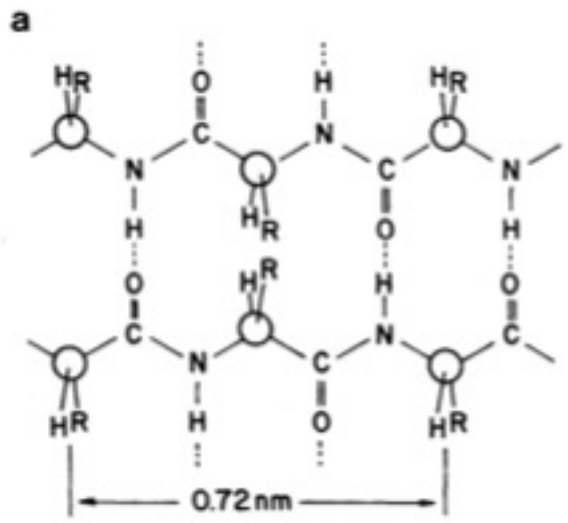


TABLE 42.1 Amino Acid Content of Collagen

Amino Acids	Content, residues/1000 residues*
Gly	334
Pro	122
Hyp	96
Acid polar (Asp, Glu, Asn)	124
Basic polar (Lys, Arg, His)	91
Other	233



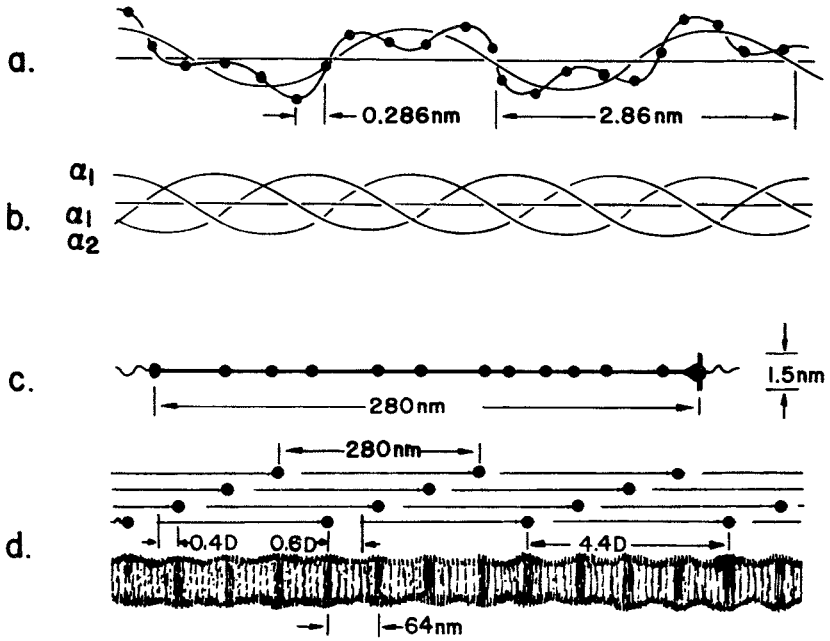
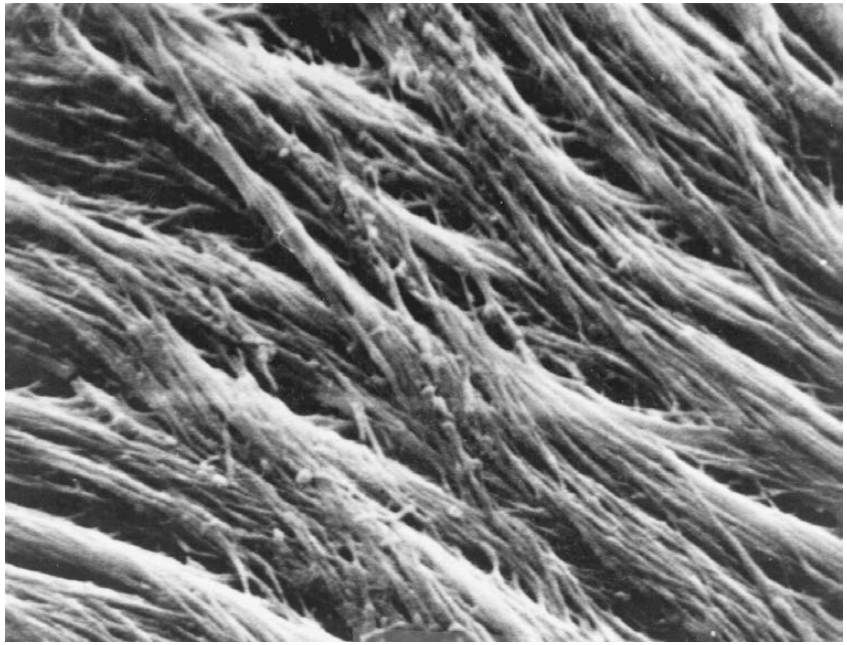
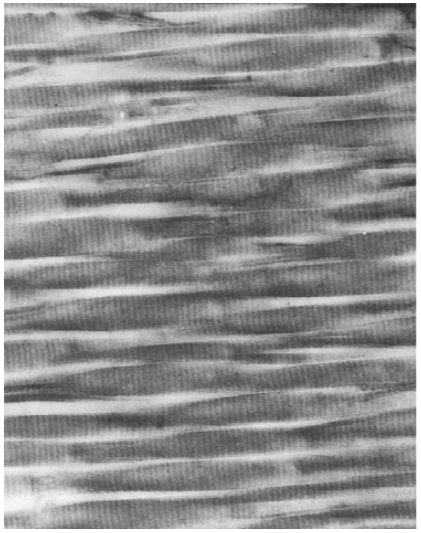


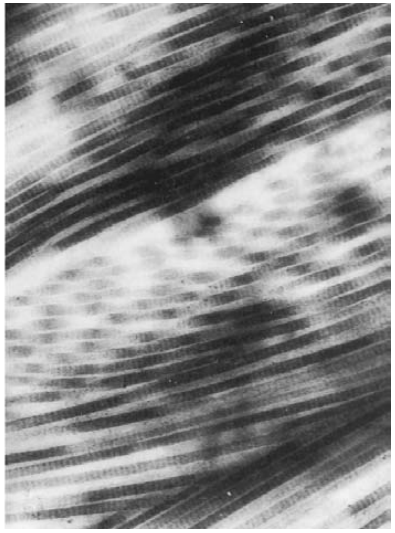
FIGURE 42.2 Diagram depicting the formation of collagen, which can be visualized as taking place in several steps: (*a*) single chain left-handed helix; (*b*) three single chains intertwined into a triple stranded helix; (*c*) a collagen (tropocollagen) molecule; (*d*) collagen molecules aligned in *D* staggered fashion in a fibril producing overlap and hole regions.



(a)



(b)



(c)

FIGURE 42.4 (*a*) Scanning electron micrograph of the surface of an adult rabbit bone matrix, showing how the collagen fibrils branch and interconnect in an intricate, woven pattern (×4800) [Tiffit, 1980]. (*b*) Transmission electron micrographs of (×24,000) parallel collagen fibrils in tendon [Fung, 1992]. (*c*) Transmission electron micrographs of (×24,000) mesh work of fibrils in skin [Fung, 1993].

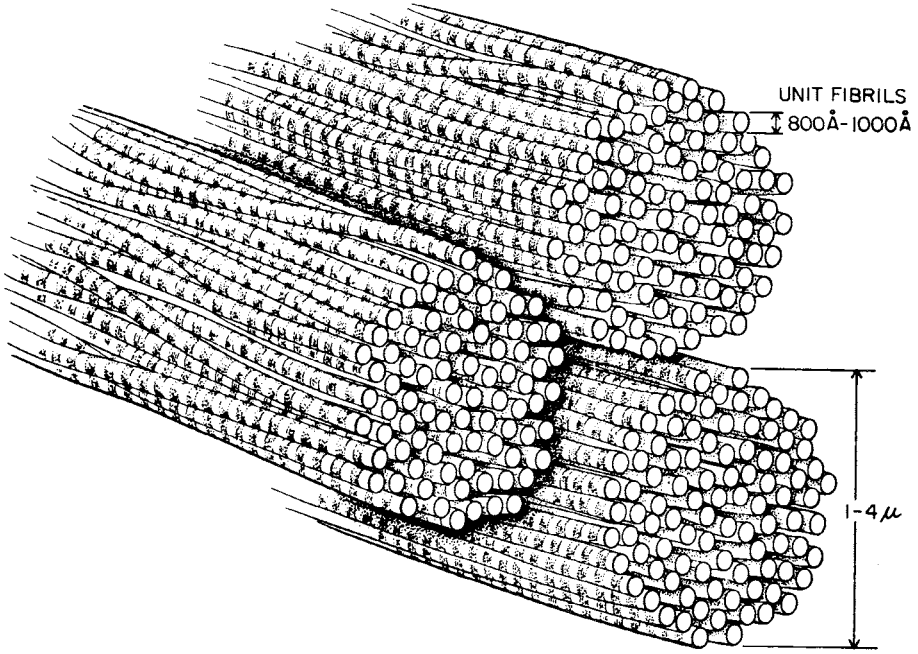
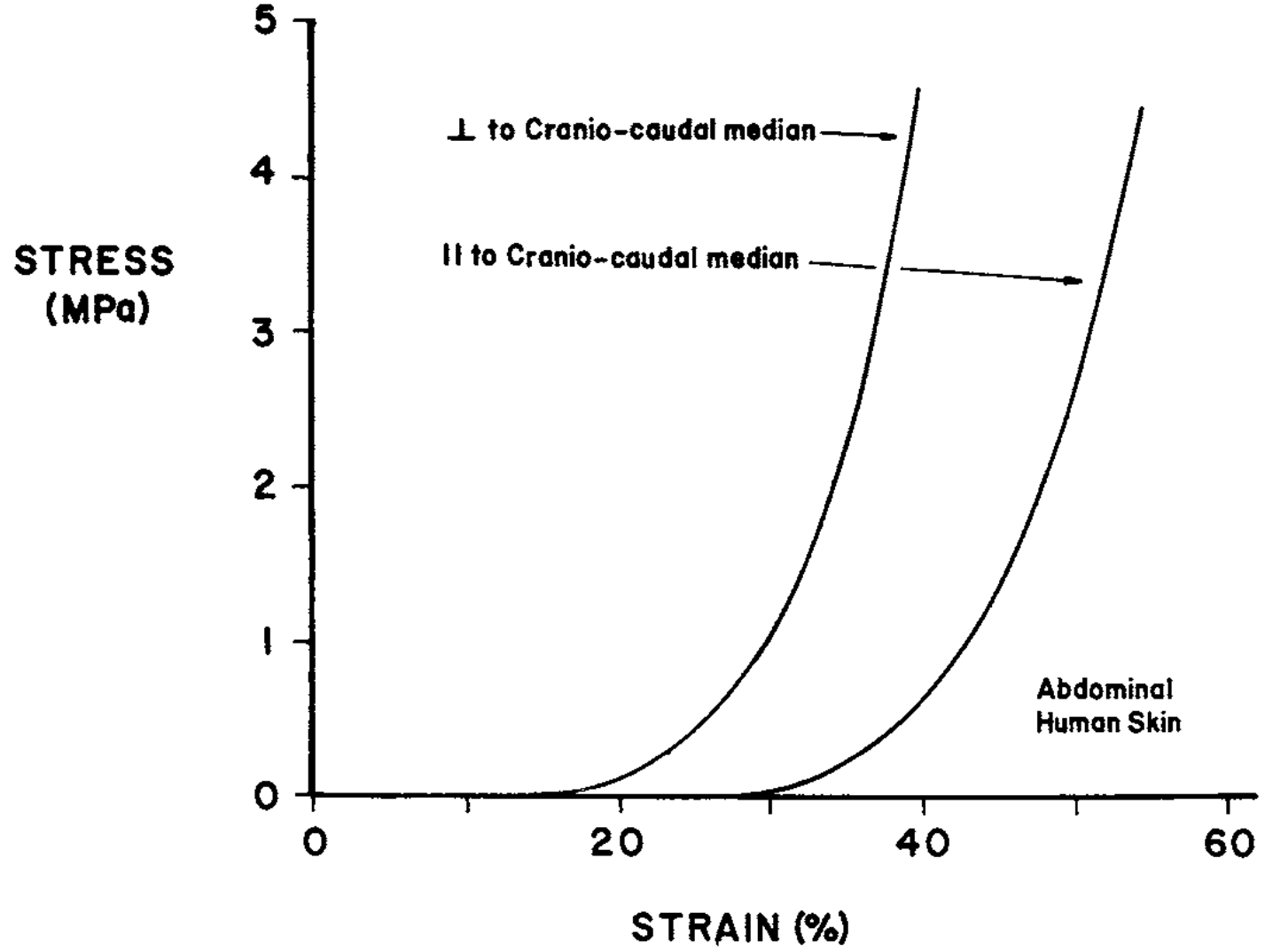


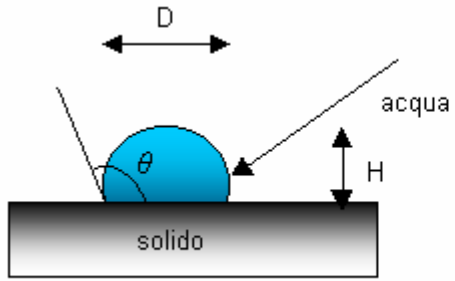
FIGURE 42.5 Diagram showing the collagen fibers of the connective tissue in general which are composed of unit collagen fibrils.

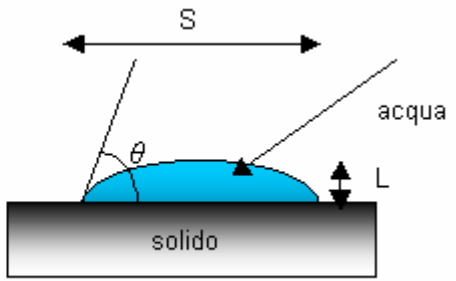

STRESS
(MPa)
5
4
3
2
1
0
⊥ to Cranio-caudal median
II to Cranio-caudal median
Abdominal
Human Skin
0
20
40
60
STRAIN (%)

Biomaterial characterisation

Contact angle measurement

Water Drop method

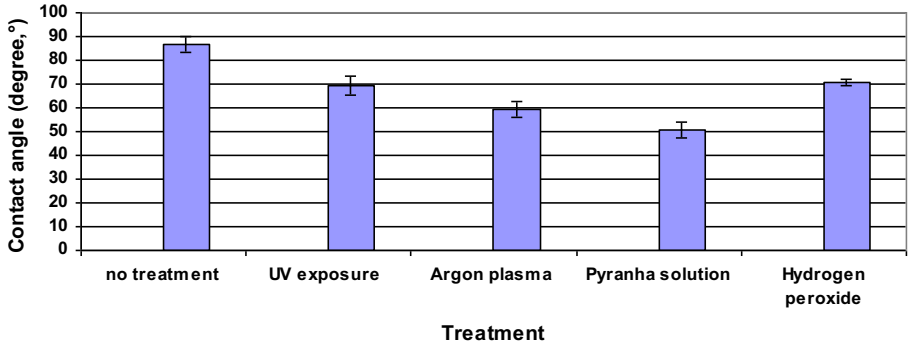




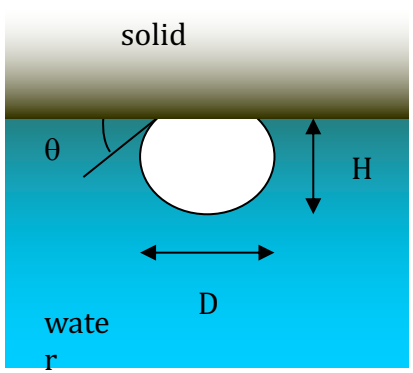
$$\theta = 180° - ar\cos\left[\left(\frac{2H}{D}\right) - 1\right]$$

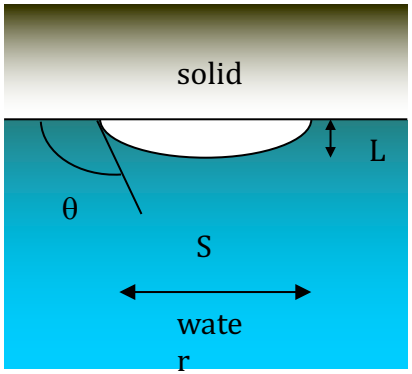
$$\theta = 2 \times arc\tan\left[\frac{2L}{S}\right]$$

Treatment inceases wettability (bubble-air on surface angle decreases)



Contact angle measurement





θ<90°
θ = arcos (2H/D –1)

θ>90°
θ = 180°- 2 arctan (2L/S)

- The measurement is based on the following principles:

1. the solid surface is rigid, unmoveable, and non-deformable. In practice, it means that elastic modulus of surface must be greater than 3.5 N/cm2;

2. the solid surface is almost smooth, so it is possible ignore the hysteris effects associated with the roughness of material;

3. the solid surface is uniform and homogenous;

4. the surface tension of the liquid is well known and constant and does not change during the experiment;

5. the solid surface does not interact with the liquid, even during the equilibrium between the three liquid-solid-aeroform phases;

6. the diffusion pressure of the liquid on the solid is zero. It means that the liquid vapours are not absorbed by the solid and so they do not alter it;

7. the solid surface is so rigid and unmoveable that the superficial groups cannot direct or equilibrate themselves after environmental changes.

The contact angle gives some information on the affinity between solid and liquid and air. The relationship between contact angle and interfacial tensing is:

$$\cos\theta = \frac{\gamma_{s/a} - \gamma_{s/l}}{\gamma_{l/a}}$$

- $\gamma_{s/a}$= interfacial solid-air tension
- $\gamma_{s/l}$= interfacial solid-liquid tension
- $\gamma_{l/a}$= interfacial liquid-air tension
- If the contact angle is small (the drop is very flat), $\cos\theta \Rightarrow 1$,and so $\gamma_s/a - \gamma_s/l = \gamma_l/a$.

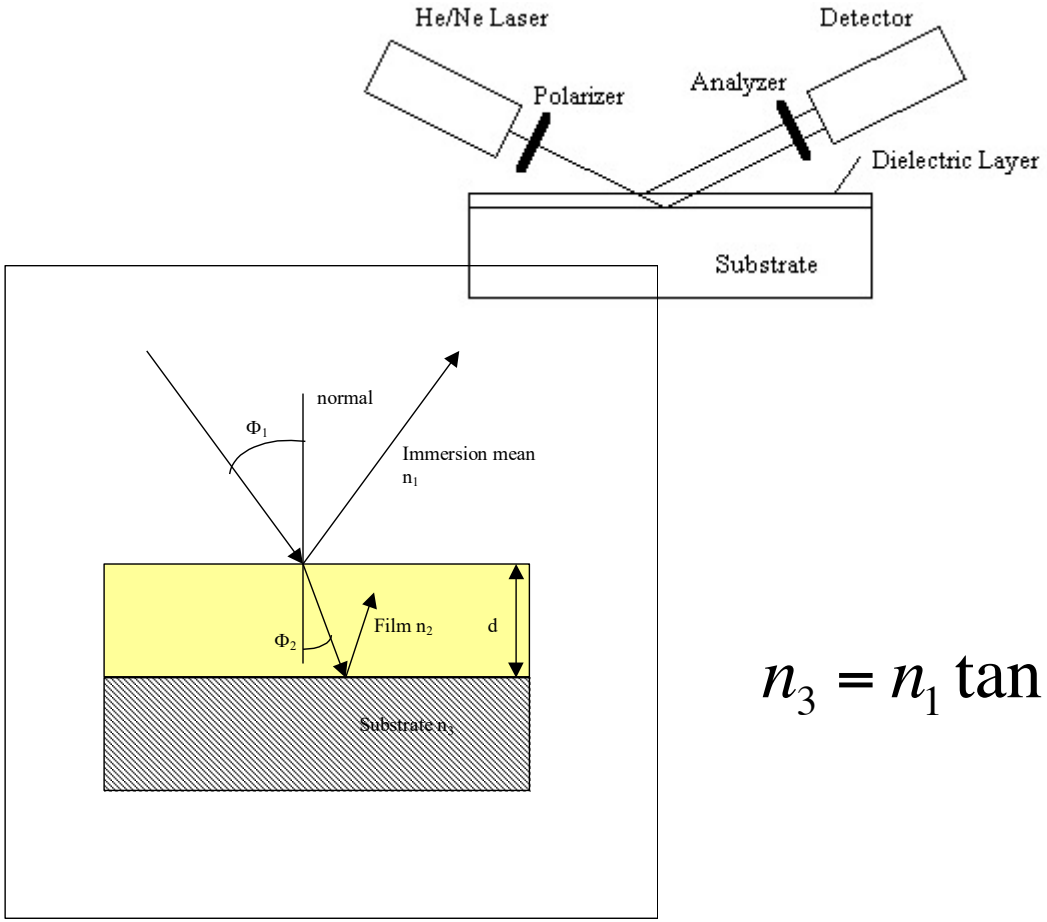
The three principal causes of hysteresis are:

1) the contamination of liquid or of the surface;
2) the presence of high roughness of material, that traps small quantities of air, altering the contact surface;
3) the rigidity of surface for which the positioning of bubble on the surface is difficult.

For these reasons, the measurements are not highly reproducible and there are variations in measured contact angle at different points on a surface.

Ellipsometry

Ellipsometry is a highly sensitive optical technique, useful for the thickness and optical density of a thin film



$$n_3 = n_1 \tan\varphi_1 \left[1 - \frac{4\rho \cdot \sin^2 \varphi_1}{(\rho+1)^2} \right]^{\frac{1}{2}}$$

Making measurements in different points of a surface, it is possible evaluate the uniformity of the layer. The lowest value of thickness that can be measured with this technique is almost an order of amplitude inferior than that measured with interferometric techniques, about 1 Angstrom.

The incident light can be separated into two components: one parallel and the other perpendicular to the plane of incidence. The reflection process introduces a phase difference Δ between these components and the variations in the ratio between their amplitudes, according to the law, where *tan* ψ represents a measure of the absorptions of the two components. For this reason, the ratio between the reflection coefficient of polarised light in the plane of incidence and that in the plane of the surface is given by:

$$\frac{|R_p|}{|R_S|}\tan\psi \qquad\qquad \rho = \frac{R_P}{R_S} = \tan\psi \cdot e^{j\Delta}$$

where ρ is the ratio between the reflection coefficients,

while ψ e Δ are functions of optical constants of surface, in other words of the wavelength of used light, the angle of incidence, thickness and refractive index of the film.

Kelvin Probe technique

It is well none that cells, owing to the nature of the cytoplasmic lipid membrane, present a small negative external electrical charge. Interaction with positive surface are thus favoured. Cells are known to make a continuous contact with positively charged substrata, whereas in general, they present only discontinuous focal contacts with negatively charged substrata.

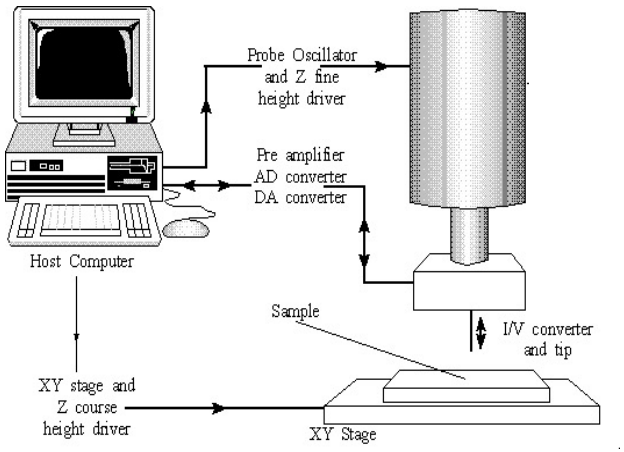
The measurement of the surface charge of a biopolymeric surface is hence an important in useful indicator of positive all-surface interaction. The measurement of the surface potential of polymer films was obtained with the Kelvin-probe technique. The Kelvin method was first postulated by the renowned Scottish scientist W. Thompson, later Lord Kelvin, in 1861.

Kelvin Probe technique

This method is based on the measurement of the potential difference between a fixed steel and vibrating plate, with and without a dielectric, positioning the two plates at a distance of a few millimetres. The difference between the two plates gives a measure of surface potential of the polymer.

The Kelvin Method is also an indirect technique for the measuring work function of a surface. The work function is the least amount of energy required to remove an electron from the surface of a conducting material, to a point just outside the metal, with zero kinetic energy. As the electron has to move through the surface region, it's energy is influenced by the optical, electric and mechanical characteristics of the region. Hence, the work function is an extremely sensitive indicator of surface condition and is affected by absorbed or evaporated layers, surface reconstruction, surface charging, oxide layer imperfections, surface and bulk contamination

Kelvin Probe technique

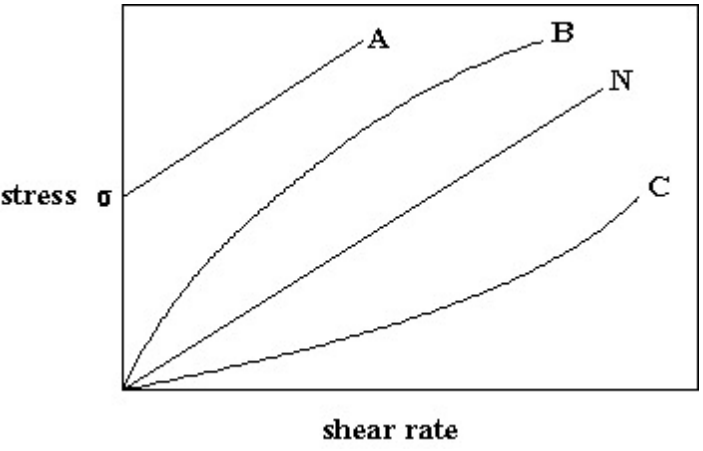


$$C = \frac{Q}{V} = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

$$\sigma = \frac{2\varepsilon_0 \varepsilon_r V}{d(\varepsilon_r - 1) + R}$$

Viscosity

The flow behaviour of polymer melts is often a very important parameter in industrial processes and is particularly relevant to injection moulding. The viscosity of the melt is the single most important characteristic to be considered when designing polymer systems for ease of injection moulding.

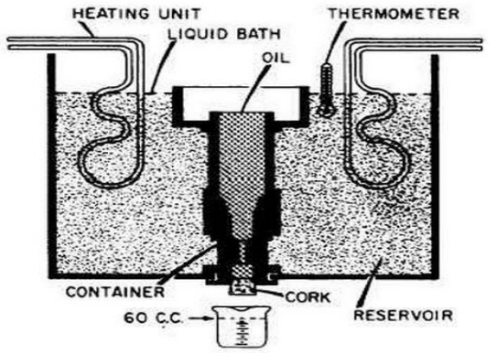


For two of the four types of viscosity behaviour illustrated stress is proportional to shear rate - these are the standard Newtonian (N) and Newtonian after a critical yield stress has been exceeded (A). The behaviour characterised by B and C is shear-rate thinning or pseudo plastic (B) and shear rate thickening or dilatent (C); several other types are possible

Saybolt Viscometer

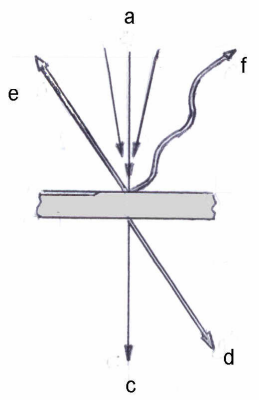
The Saybolt viscometer**.** It consists of a cylindrical container for the polymer solution under examination with a receiving flask under it to catch and measure polymer solution discharged from the container. At the bottom of the container is an orifice of specified dimensions through which the polymer flows. The container is jacketed with a water bath to facilitate maintenance of a constant temperature. Two thermometers check temperatures, one in the polymer solution and one in the water bath. To adjust the temperature, an external source of heat is applied to the bath. Flow of polymer solution into the receiver is timed with a stop watch or equivalent device. The time of flow is taken to be proportional to the viscosity of the fluid.Viscosity is a linear function of temperature and it is possible express it as:

$\mu = aT + b$.

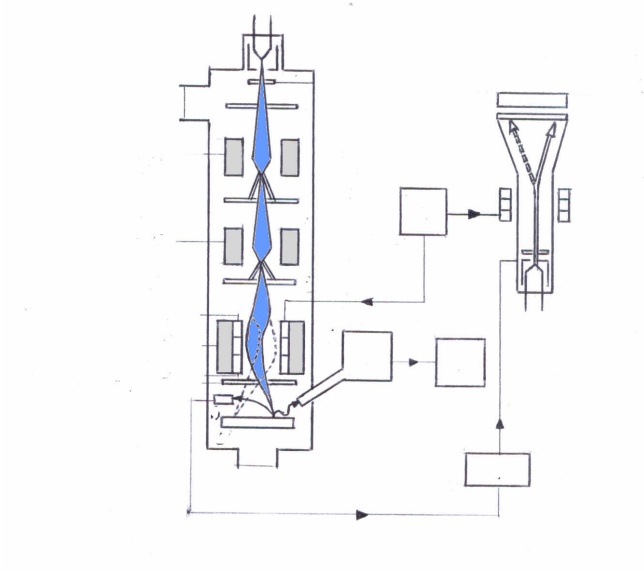


Scanning electrical Microscopy

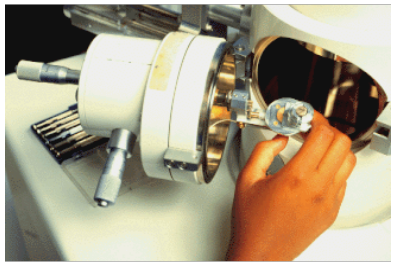
Scanning electronic microscopy allows the use of a wide range of magnifications, between 15 until 500000. When a beam of electrons hits the surface of a material a part of these incident electrons, called primary electrons, preserve their energy and are reflected, (retrodiffusive electrons) (*e* in figure), while the other loose their energy by transferring it to the electrons of the solid, (*a, c* in figure). A fraction of electrons are then emitted with lower energy (*f, d* in figure).



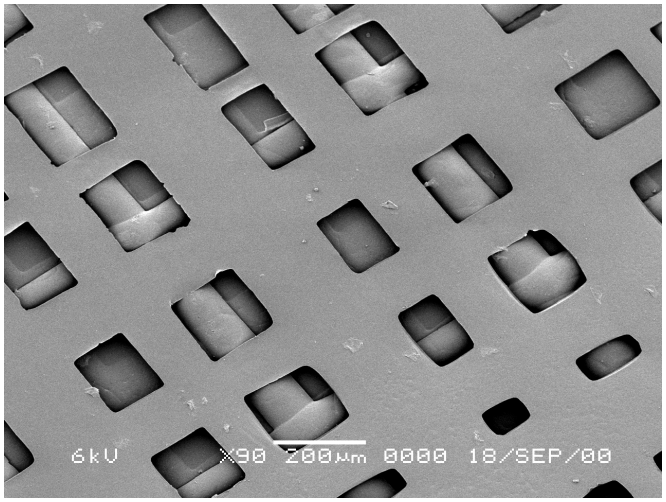
Scanning electrical Microscopy

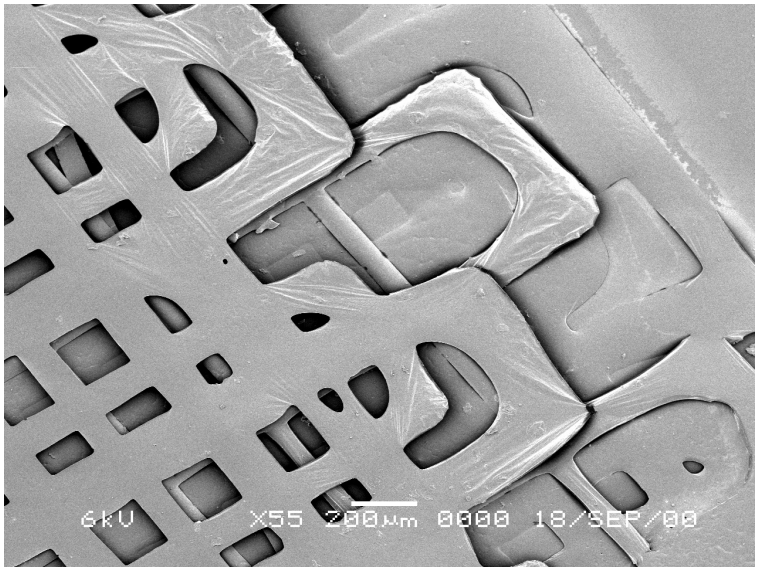


The incident electrons have high energy; they are able to ionise the interior energy levels of atoms of the material then go back to the fundamental state with photon emission. The X rays produced have energies that are characteristic of the atoms that emit them, and so they can be utilised to obtain information on the chemical composition of the sample. With an X-ray spectrum analyser, it is possibly have a spectrum that gives the relative peaks of the different elements. The intensity of characteristic line of one element is directly proportional to its concentration.



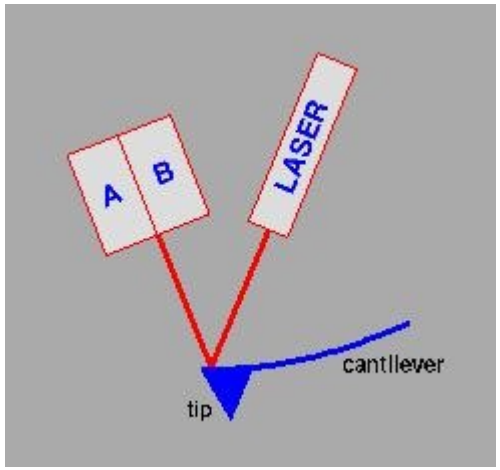
Scanning electrical Microscopy





Atomic Force Microscopy

Binnig, Quate and Gerber invented the atomic force microscope (AFM) or scanning force microscope (SFM) in 1986. Like all other scanning probe microscopes, the AFM utilises a sharp probe moving over the surface of a sample in a raster scan. In the case of the AFM, the probe is a tip on the end of a cantilever, which bends in response to the force between the tip and the sample



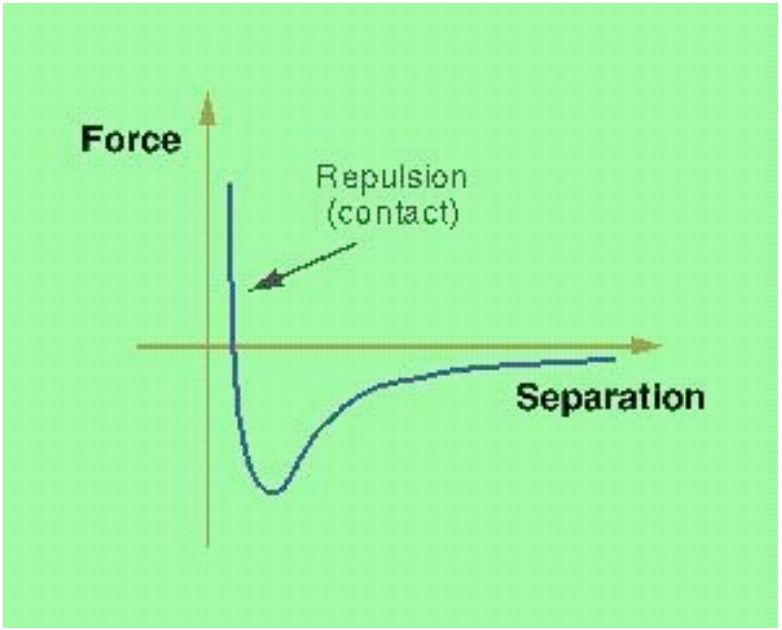
The figure illustrates how this works; as the cantilever flexes, the light from the laser is reflected onto the split photo-diode. By measuring the difference signal (A-B), changes in the bending of the cantilever can be measured. Since the Cantilever obeys Hooke's Law for small displacements, the interaction force between the tip and the sample can be found. An extremely precise positioning device made from piezoelectric ceramics, most often in the form of a tube scanner performs the movement of the tip or sample. The scanner is capable of sub-angstrom resolution in x-, y- and z-directions. The z-axis is conventionally perpendicular to the sample.

Atomic Force Microscopy

The way in which image contrast is obtained can be achieved in many ways. The three main classes of interaction are *contact mode*, *tapping mode* and *non-contact mode*.

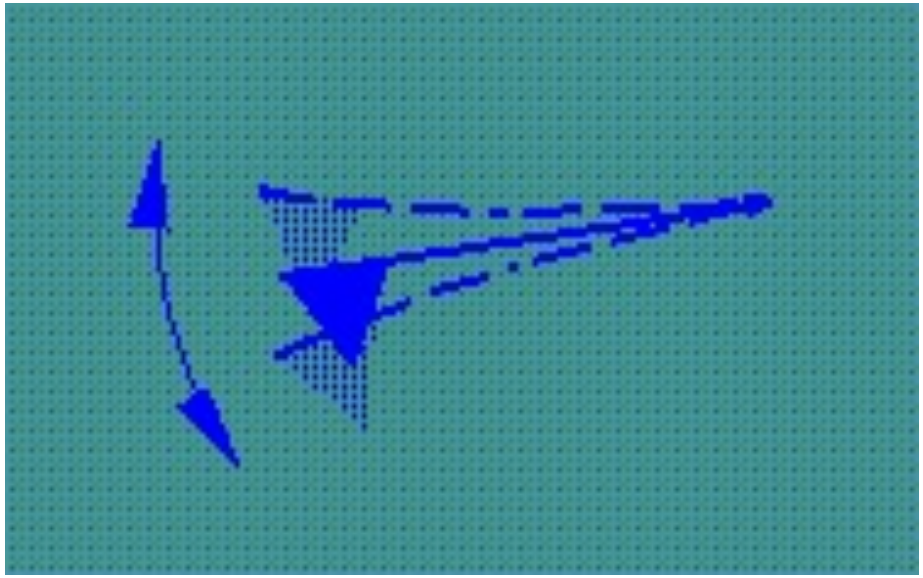
Contact mode is the most common method of operation of the AFM. As the name suggests, the tip and sample remain in close contact as the scanning proceeds. By "contact" we mean in the repulsive regime of the inter-molecular force curve.

The repulsive region of the curve lies above the x-axis. One of the drawbacks of remaining in contact with the sample is that there exist large lateral forces on the sample as the drip is "dragged" over the specimen.



Atomic Force Microscopy

Tapping mode is the next most common mode used in AFM. When operated in air or other gases, the cantilever is oscillated at its resonant frequency (often hundreds of kilohertz) and positioned above the surface so that it only taps the surface for a very small fraction of its oscillation period. This is still contact with the sample in the sense defined earlier, but the very short time over which this contact occurs means that lateral forces are dramatically reduced as the tip scans over the surface. When imaging poorly immobilised or soft samples, tapping mode may be a far better choice than contact mode for imaging.



Atomic Force Microscopy

Non-contact operation is another method, which may be employed when imaging by AFM. The cantilever must be oscillated above the surface of the sample at such a distance that we are no longer in the repulsive regime of the inter-molecular force curve. This is a very difficult mode to operate in ambient conditions with the AFM. The thin layer of water contamination, which exists on the surface on the sample, will invariably form a small capillary bridge between the tip and the sample and cause the tip to "jump-to-contact". Even under liquids and in vacuum, jump-to-contact is extremely likely, and imaging is most probably occurring using tapping mode.

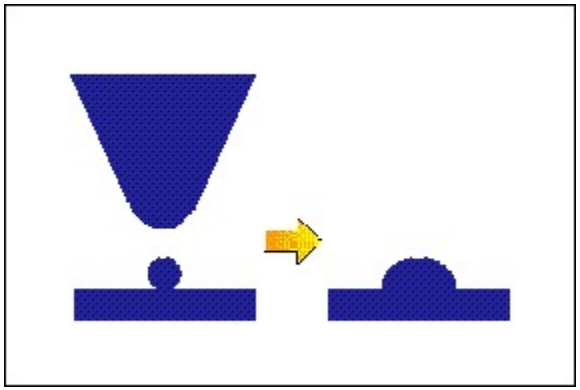
Atomic Force Microscopy

One of the most important factors influencing the resolution, which may be achieved with an AFM, is the sharpness of the scanning tip. The first tips used by the inventors of the AFM were made by gluing diamond onto pieces of aluminium foil. Commercially fabricated probes are now universally used. The best tips may have a radius of curvature of only around 5nm. The need for sharp tips is normally explained in terms of *tip convolution*. This term is often used (slightly incorrectly) to group together any influence, which the tip has on the image. The main influences are:

- broadening
- Compression
- interaction forces
- aspect ratio

Tip broadening arises when the radius of curvature of the tip is comparable with, or greater than, the size of the feature trying to be imaged. The diagram illustrates this problem; as the tip scans over the specimen, the sides of the tip make contact before the apex, and the microscope begins to respond to the feature. This is what we may call tip convolution.

Compression occurs when the tip is over the feature trying to be imaged. It is difficult to determine in many cases how important this affect is, but studies on some soft biological polymers (such as DNA) have shown the apparent DNA width to be a function of imaging force.



Atomic Force Microscopy