Biomaterials Engineering and Prosthesis Branch

Fourth Class

Second Course

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Bio-composite Materials

Part-2

By

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References

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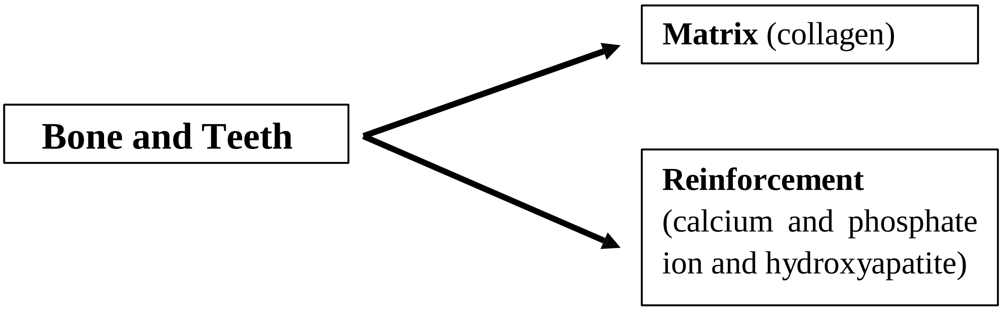
Bio-composite Materials

The term ‘Bio-composites’ refers to the composites that can be employed in bioengineering which are contain two or more different constituents' materials or phases, on a scale larger than the atomic (macroscopic scale).

The bones, cartilage, tendons, skin, ligaments, teeth, etc. are natural composite structures in the human body. From (collagen) as matrix material and calcium and phosphate ion and hydroxyapatite as reinforcing materials.



These natural composite have anisotropic properties (material properties that are the different in every direction at a point in the body). The anisotropy of the elastic properties of the biological tissues has to be considered in the design for implants made from composite biomaterials.

Natural composites have hierarchical structures particulate, porous and fibrous structural features which are seen on different micro-scales. The amount, distribution, morphology and properties of structure components determine the final behavior of resultant tissues or organs.

Some synthetic composites can be used to produce prosthesis which able to simulate the tissues, to solve the problem, with good their mechanical behavior and to restore the functions of the damaged tissues.

The factors that are largely affected to the properties of biomedical composites represent by: shape, size, distribution, volume fraction, bioactivity properties of the reinforcement or matrix phases; in addition to molecular weight of matrix and interfacial situation between the reinforcement and matrix.

Using of Bio-composites Materials

1- Hard tissue applications, which including:

a- Dental applications for example:

1- Dental filling such as polymer matrix filled with barium glass or silica.

2- Arch wire.

3- Dental implant.

4- Denture base materials.

b- Joint prostheses fixation for example: bone particles or carbon fibers reinforced methyl methacrylate bone cement and ultra-high molecular weight polyethylene.

c- Orthopedic implants with porous surface for example: external fixator (prosthetic socket), bone plate, total hip replacement, artificial leg, cages for spinal (herniated disk), composite screws and pins.

2- Soft tissue applications, which including:

a- Artificial tendon.

b- Artificial ligament.

c- Artificial Cartilage.

d- Artificial arteries (vascular graft).

e- Rubber are usually filled with very fine particles of silica to improve the properties of rubber to use in catheters and rubber gloves.

Advantages of Bio-composite

1- Good durability in small to moderate restorations.

2- High biocompatibility.

2- Moderate resistance to wear and corrosion.

4- Inert.

5- Provides high fracture toughness.

6- Resistance against fatigue failure.

7- Bio composites are highly biocompatible with modern diagnostic methods, magnetic resonance imaging (MRI).

8- Their combinations of low density/weight that make them ideal materials for such as applications.

9- Polymer composites offer low modulus but high strength, these properties suitable for some orthopedic application.

10- For dentistry, composites offer better aesthetic characteristic and more economical than metal, that suitable for some dentistry application.

Disadvantages of Bio- composite

1- Each constituent of the composite must be biocompatible.

2- Water absorption in case of polymer composite causes a reduction in stiffness and others mechanical properties.

3- The degradation of interface between components is also problem which must be avoided.

Particulate Bio-composite Materials

The particle reinforcement has been improving the properties of bone cement such as stiffness and fatigue life. And the rubber reinforcing with very fine silica particles to make the strong and tough rubber materials are used in catheter and gloves applications. Also, the denture base materials consist of PMMA matrix reinforcing with stiff inorganic materials to make high stiffness and high wear resistance of dental composite.

The ceramic particulate reinforcement has led to the choice of more materials for implant applications that include ceramic/metal, ceramic/polymer, ceramic/ceramic composites. While in ceramic/metal the metals face corrosion related problems, although when ceramic coatings on metallic implants, but degrade as the time progress during long time applications.

In ceramic/polymer, the biocompatible polymers have been mostly applied as matrix for composite materials associated with ceramic fillers in tissue engineering. Although the polymers are known to be flexible and exhibit low mechanical strength and stiffness, but the ceramics are generally stiff and brittle materials, Composites aim to combine the properties of both materials for medical applications.

Ceramic/ceramic composites enjoy superiority properties due to similarity with bone materials, exhibiting biocompatibility and able to be shaped into definite size. The composite materials that made from bioinert and bioactive ceramics are produced to achieve two important features, bioactivity and mechanical strength. Such as alumina ceramic can form composites with hydroxyapatite that are bioactive with high strength that it can form osteointegration with bone.

The stress in one of the components of a two phase composite can be calculated from the equation:

$$\boldsymbol{\sigma} = \frac{\mathbf{E_1 * P}}{\mathbf{E_1 * A_1 + E_2 * A_2}}$$

Where *P* is the total load on the structure and *E* and *A* are the Young's modulus and cross-sectional area of each of the components. The applied load can be assumed to be the same before and after implantation, therefore the following equations for the stress in the bone in the two configurations:

Preimplantation (*E*implant = 0; *A*implant = 0): $\boldsymbol{\sigma}_{\mathbf{bone}} = \frac{\mathbf{E_{bone} * P}}{\mathbf{E_{bone} * A_{bone}}} = \frac{\mathbf{P}}{\mathbf{A_{bone}}}$

Post implantation: $\boldsymbol{\sigma} = \frac{\mathbf{E_{bone} * P}}{\mathbf{E_{bone} * A_{bone} + E_{implant} * A_{implant}}}$

The implants with a higher modulus and a larger cross-sectional area will shield the bone.

Fibrous Bio-composite Materials

Two types of fibers can be use as reinforcing materials, synthetic fiber such as (glass, Kevlar, carbon and ceramic) and natural fiber such as (animal fibers, vegetable fibers and mineral fibers).

When the fibers incorporated in a polymer matrix are mechanically more effective in achieving increase stiffness, strength, fatigue life, and other properties more effective than particulate composite. For that reason, carbon fibers have been incorporated in the high-density polyethylene (HDPE) used in total knee replacements. Also use of ultrahigh molecular weight polyethylene (UHMWPE) in these implants is due to providing adequate wear resistance.

Also the fibers have been incorporated into poly methyl methacrylate (PMMA) as bone cement basis that led to significant improvements of mechanical properties. Furthermore, the metal wires have been used as macroscopic "fibers" to reinforce PMMA cement which is used in spinal stabilization surgery.

Bounds of properties of bio-composites

$\mathbf{E_{II} = E_i * V_i + E_m * (1 - V_i)}$ In the longitudinal direction of fibers (upper bound)

$\frac{1}{E_\perp} = \frac{V_i}{E_i} + \frac{(1-V_i)}{E_m}$ In the lateral direction of fibers (lower bound)

Table (1) represent the examples of fiber reinforced composite for bone replacements. In fibrous composite failure may be occur:

1- Fiber breakage.
2- Matrix cracking.
3- Debonding of fibers from matrix.

More than 50 processes depending upon the type and nature of fiber and matrix using to manufacturing fibrous bio-composite materials such as:

- Hand Lay-Up.
- Spray Lay-Up.
- Vacuum Bagging.

General requirement of bio-composite reinforcements

To ensure reinforcement of bio-composite materials, when combination of particles or fibers with resin matrix must be fulfill certain to its used in dentistry and medicine applications:

1- Good wetting or adsorption bond between the polymer and reinforcing materials.
2- The coefficient of thermal expansion is not too widely mismatch.
3- The matrix must permit large deformation without breakage.
4- The matrix can withstand the strong and stresses at the interface region.
5- The matrix should not be brittle to resist crack propagation through the polymer when the material is stressed, because they are able to dissipate large amounts of elastic energy.

If above conditions are fulfilled and reinforcing materials has higher modulus of elasticity, can be overcome the limitation in physical and mechanical properties of polymer.

Table (1): Examples of fiber reinforced composites for bone replacement.

Carbon fiber
Epoxy resin.
PMMA.
Polysulfone.
Polycarbonate.
Polvetheretherketone.
Polylaetide.
Aramid (Kevlar)
PMMA.
Polysulfone.
Polycarbonate.
Polyethylen fiber
PMMA.
Poly (DL-lactic acid).
Bioactive glass fiber
Polysulfone.
Calcium metaphosphate glass fiber
Polylactide.
Calcium phosphate glass fiber
Poly (L-lactide).
Poly caprolactone.
Poly -(desamino-tyrosyl-tyrasine ethyl ester.
Calcium-sodium-metaphosphate glass fiber
Polyester.
Titanium fiber
PMMA.

Rules of Mixtures

Amounts of cold cure acrylic resin (powder and monomer) and amounts of reinforced materials, (particles and fibers) were weighed, and the volume fraction of these materials was calculated according to the following equation:

$$\rho_c = \sum \rho_i V_i \qquad (1)$$

$$v_c = \sum v_i V_i \qquad (2)$$

$$V_P = \frac{v_P}{v_C} \Longrightarrow v_P = \frac{m_P}{\rho_P} \qquad (3)$$

$$V_F = \frac{v_f}{v_C} \Longrightarrow v_f = \frac{m_f}{\rho_F} \qquad (4)$$

$$V_m = \frac{v_m}{v_c} \Longrightarrow v_m = \frac{m_m}{\rho_m} \qquad (5)$$

Where:

ρ_i: Density of constituent's composite material.

m_p m_f m_m: Mass of particles, fibers and matrix respectively (gm).

v_P v_f v_m v_C: Volume of particles, fibers, matrix and composite materials respectively (cm^3).

ρ_P ρ_f ρ_m: Density of particles, fibers and matrix respectively (gm/cm^3).

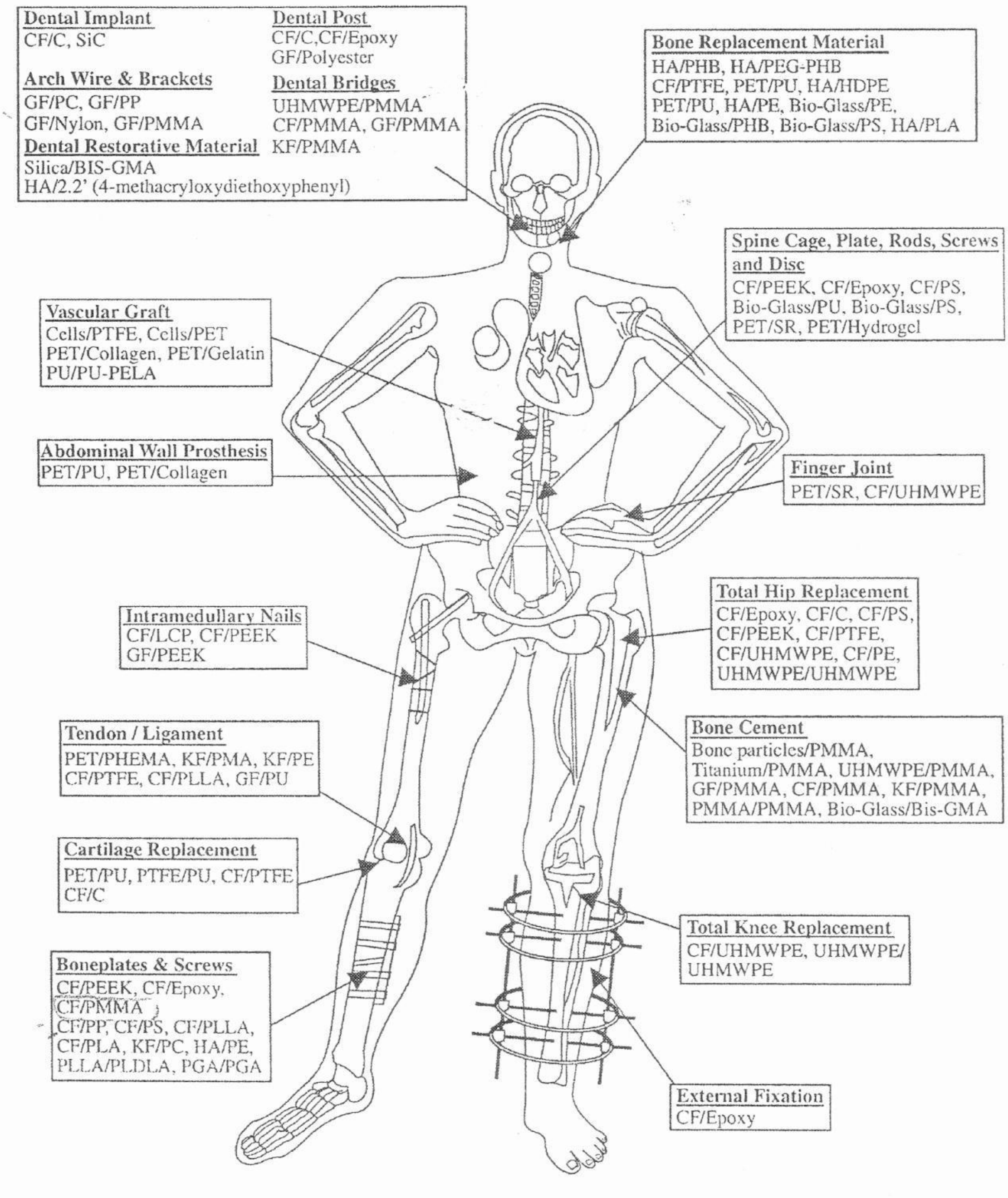
V_P V_F V_m: Volume fraction of particles, fibers and matrix respectively.

V_i: Volume fraction of constituent's composite material.

Porous Materials

Porous materials have a high ratio of surface area to volume. Porous materials, are used as implants in hard tissue, (like hydroxyapatite), and used in soft tissue applications include polyurethane, polyamide, and polyester. Porous structure that is obtained through powder sintering, further reduces elastic modulus to get closer to that of cortical bone.

The figure below represents the various applications of polymer composite materials as biomaterials for bone replacement.



CF: Carbon fibers, C: Carbon, GF: Glass fibers, KF: Kevlar fibers, PMMA: Polymethymethacrylate,
PS: Polysulfone, PP: Polypropylene, UHMWPE: Ultra-high-molecular weight polyethylene,
PLDLA: Poly(L-DL-lactide), PLLA: Poly (L-lactic acid), PGA: Polyglycolic acid, PC: Polycarbonate,
PEEK: Polyetheretheketone; HA: Hydroxyapatite, PMA: Polymethylacrylate,
BIS-GMA: bis-phenol A glycidyl methacrylate, PU: Polyurethane, PTFE: polytetrafluoroethylene,
PET: polyethyleneterephthalate, PEA: poltethylacrylate, SR: silicone rubber,
PELA: Block co-polymer of lactic acid and polyethylene glycol, LCP: liquid crystalline polymer,
PHB: Polyhydroxybutyrate, PEG: polyethyleneglycol,
PHEMA: poly(20hydroxyethyl methacrylate)

Fig. Various applications of different polymer composite biomaterials.

General Applications of Bio-composite Materials

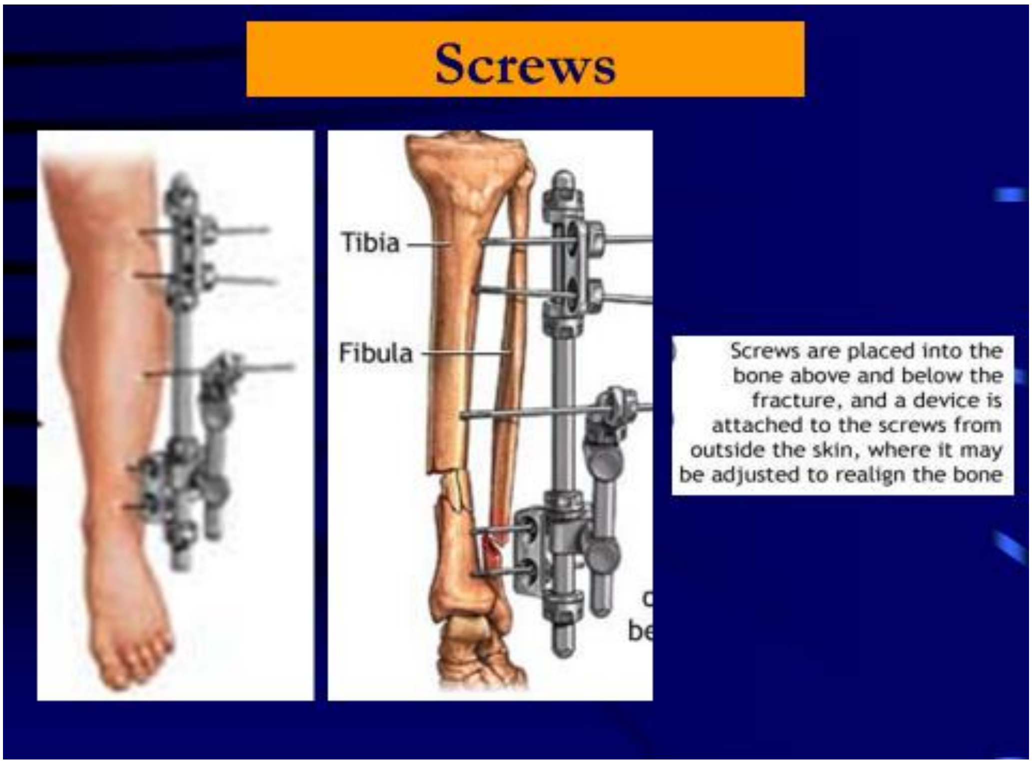
Dental filling

Denture Base Materials

Internal Bone Plat Fixation

External Fixation

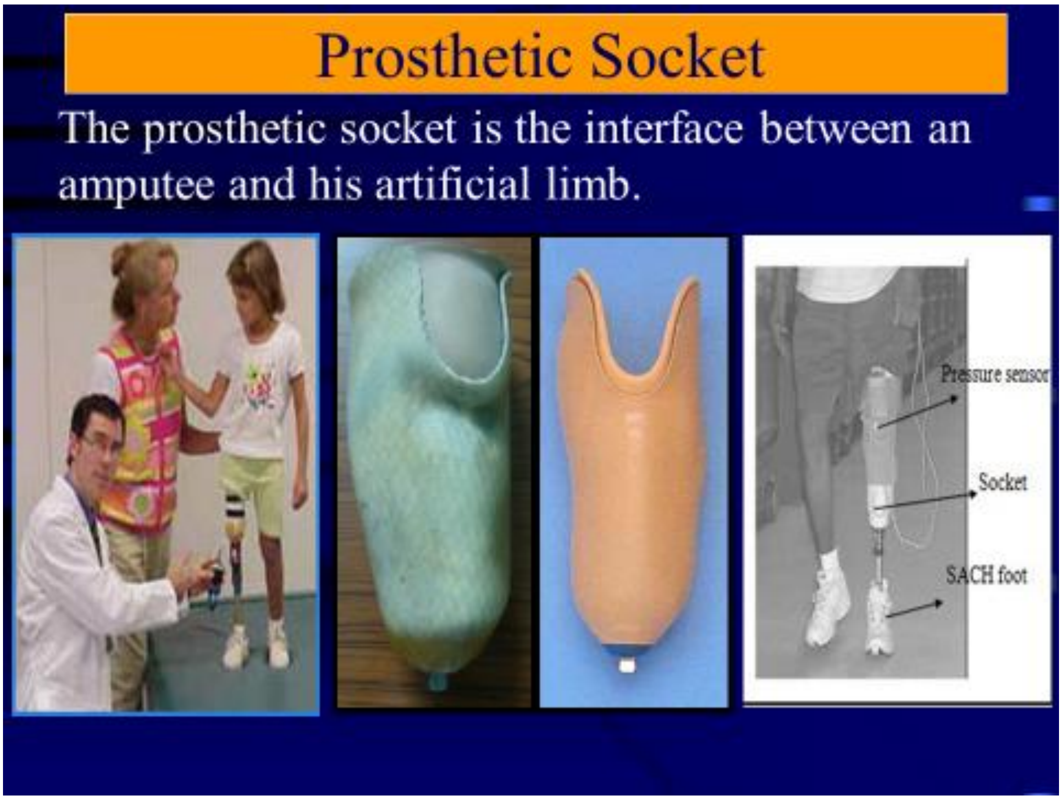
Number of Pins
- Two per segment
- At least 3 pins



Screws

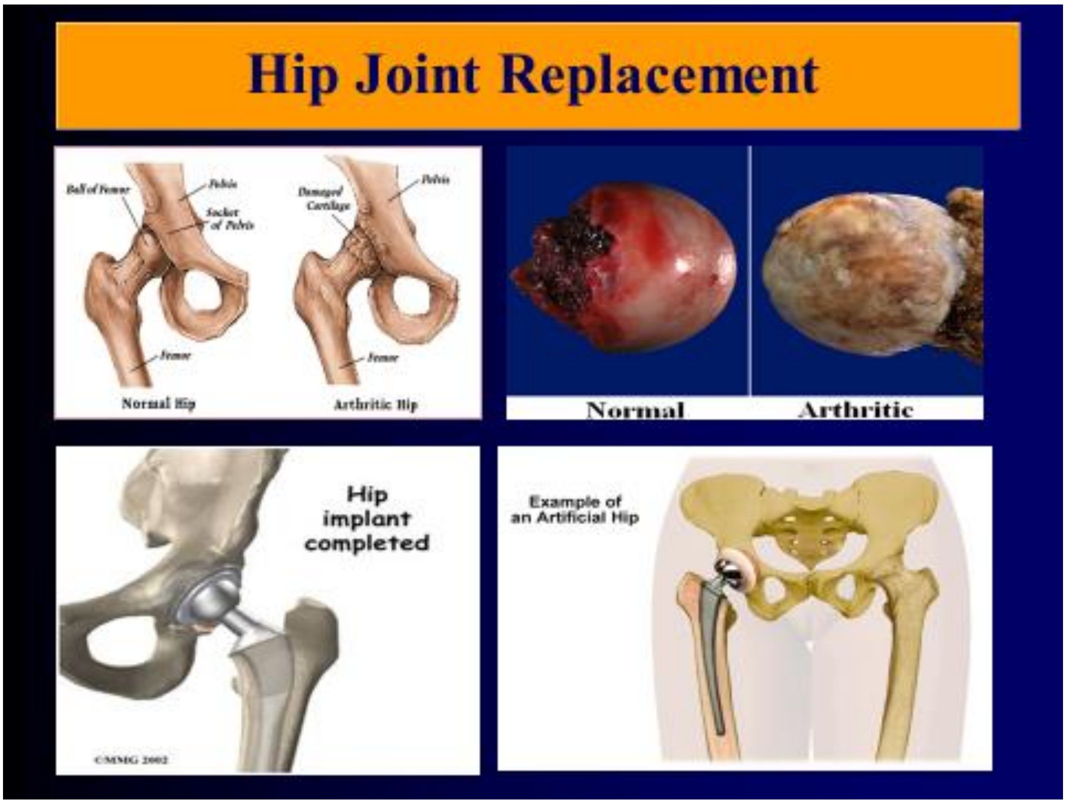
Screws are placed into the bone above and below the fracture, and a device is attached to the screws from outside the skin, where it may be adjusted to realign the bone

Artificial Legs Replacement



Prosthetic Socket

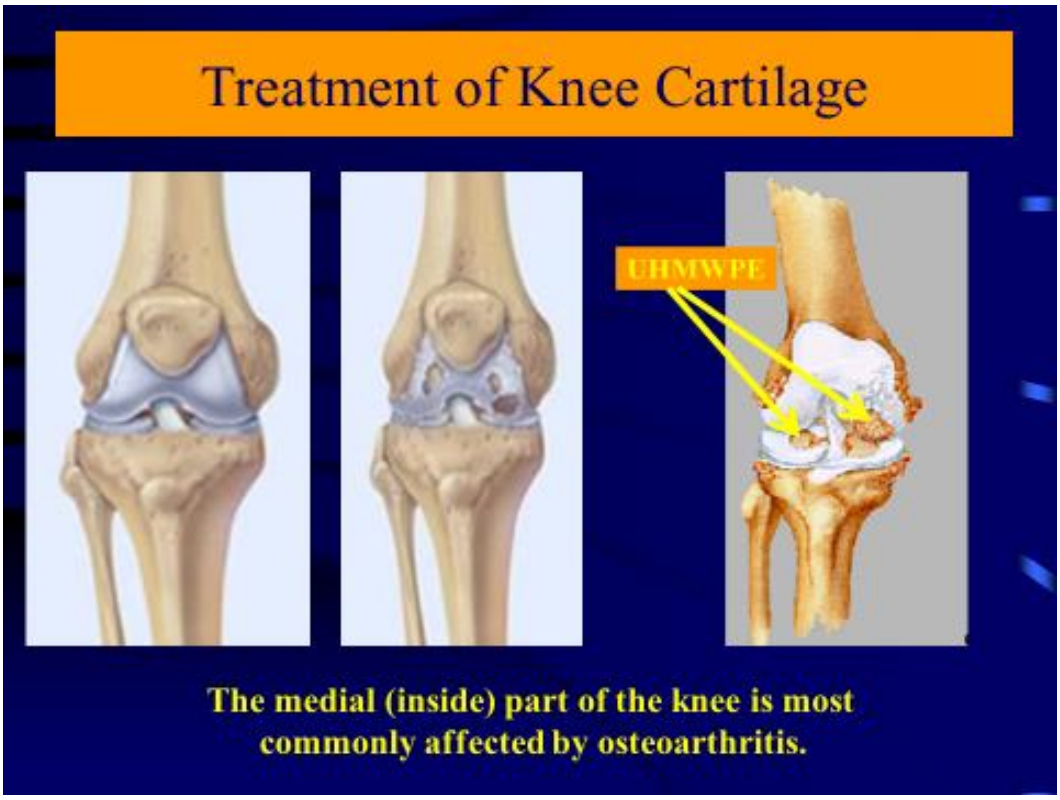
The prosthetic socket is the interface between an amputee and his artificial limb.



Hip Joint Replacement

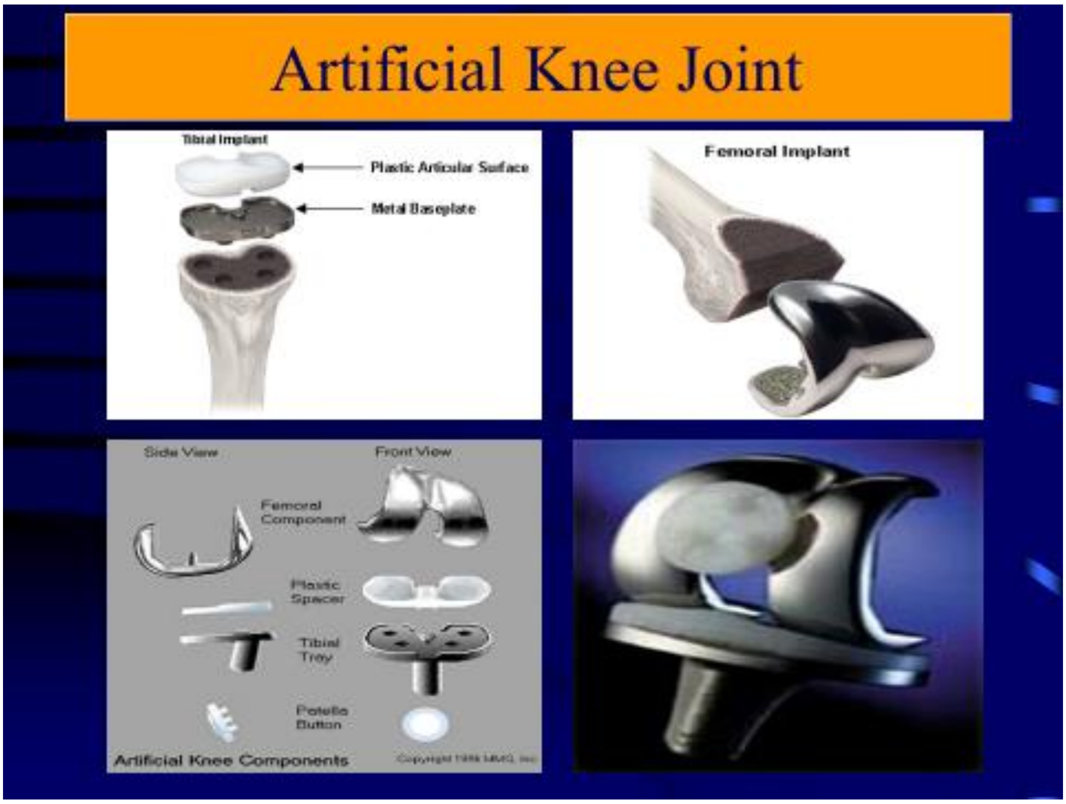
Artificial Hip Joints

Knee joint prostheses

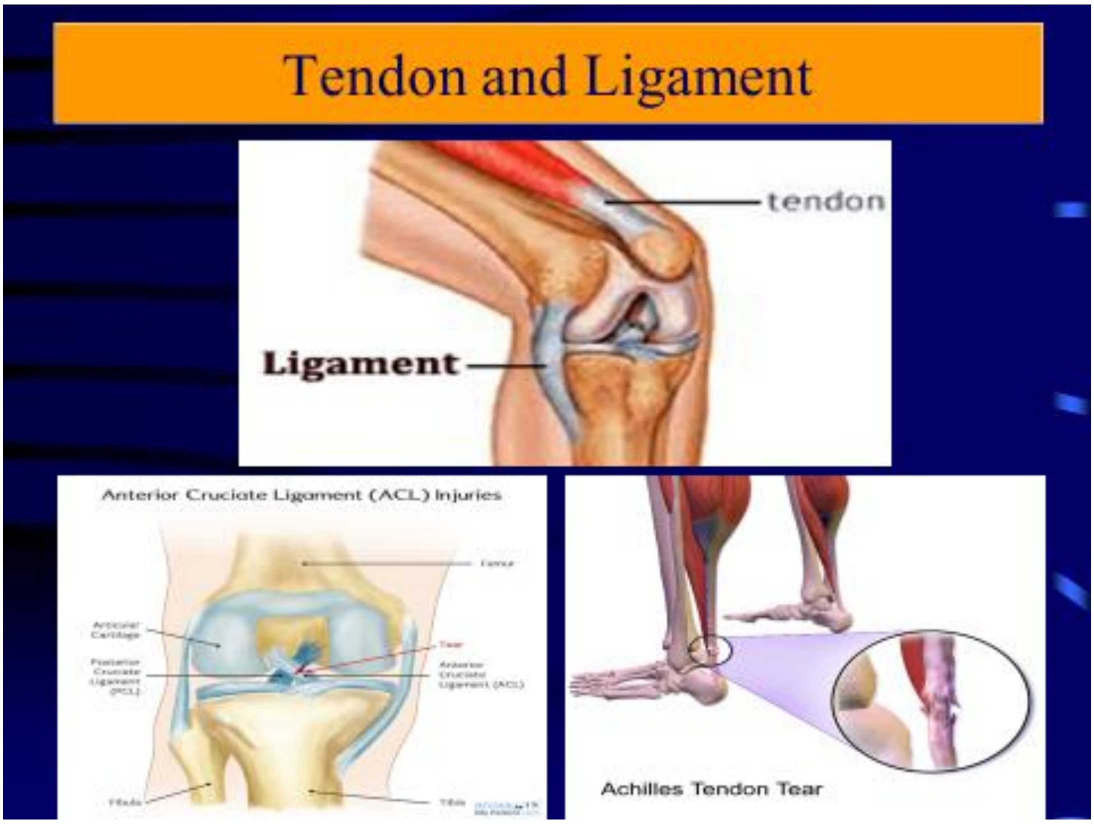


Treatment of Knee Cartilage

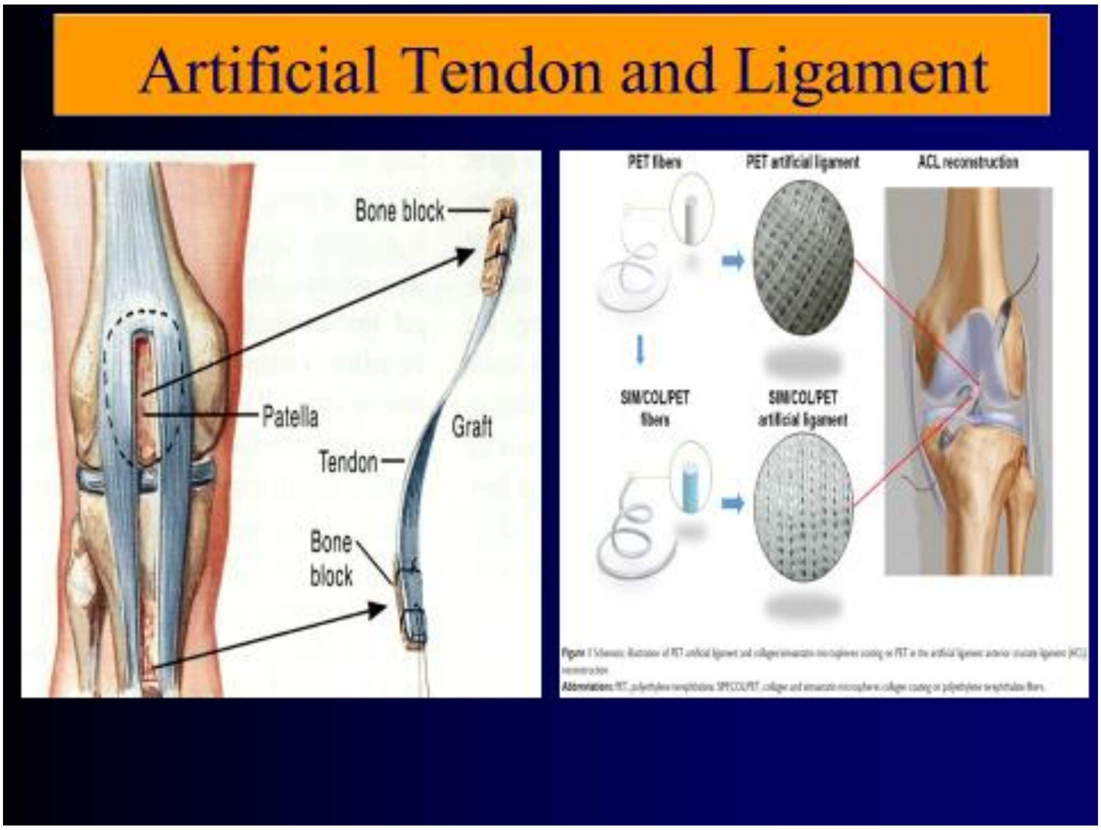
The medial (inside) part of the knee is most commonly affected by osteoarthritis.



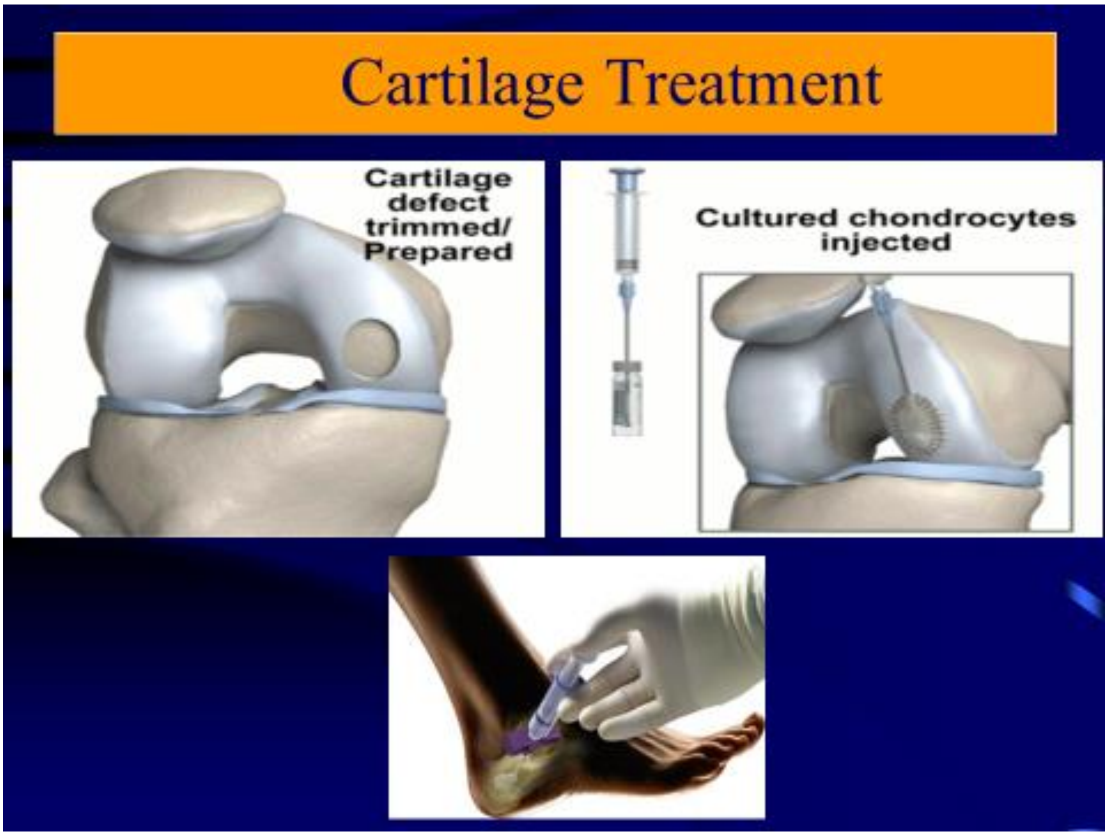
Artificial Knee Joint



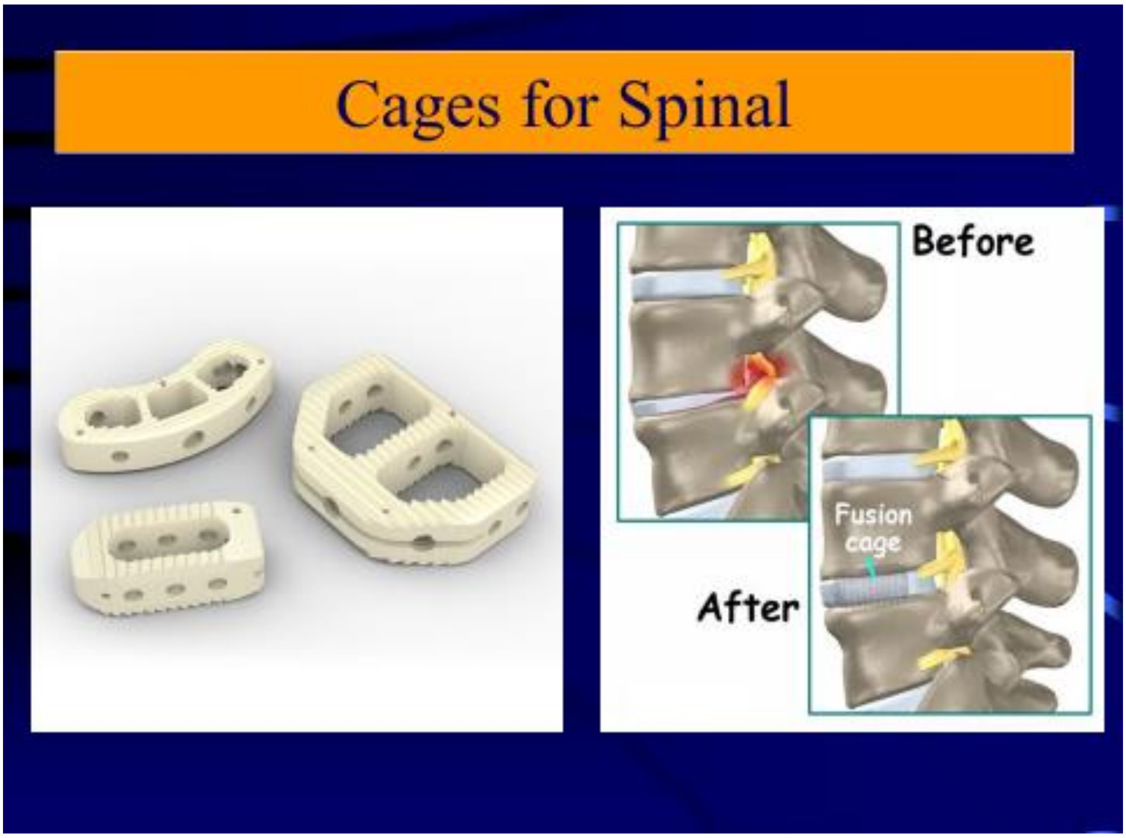
Tendon and Ligament



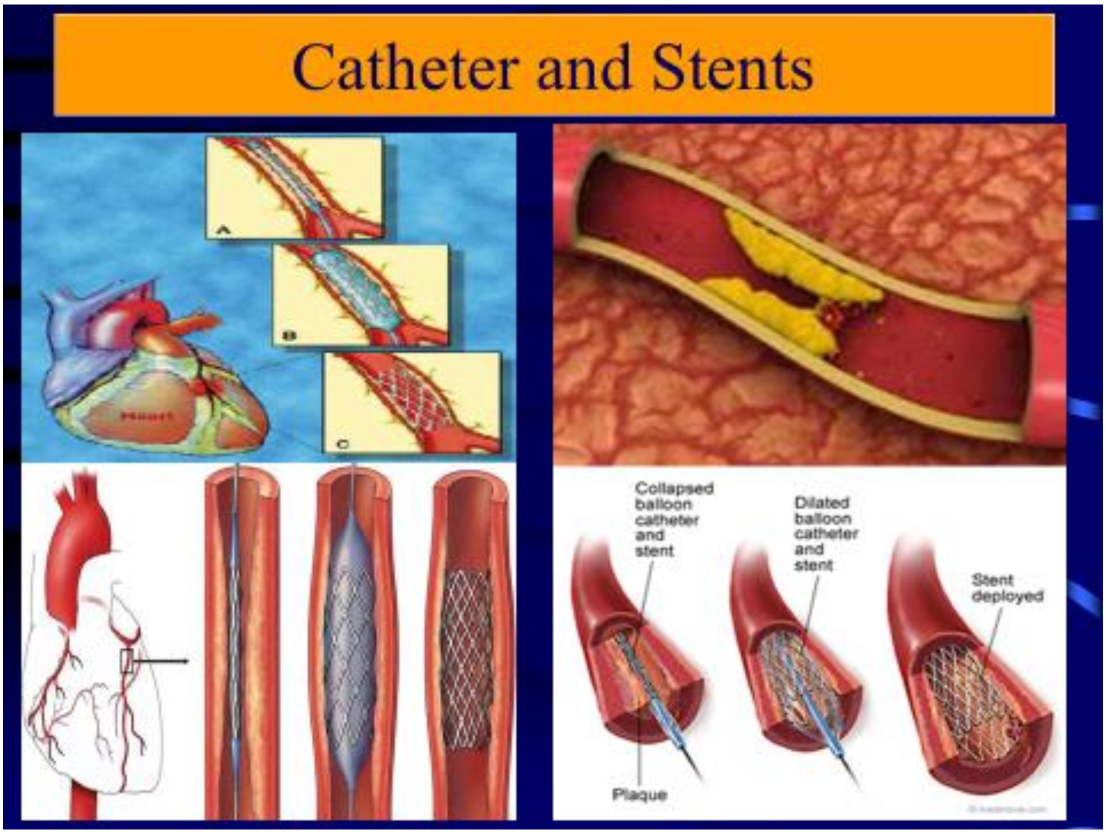
Artificial Tendon and Ligament



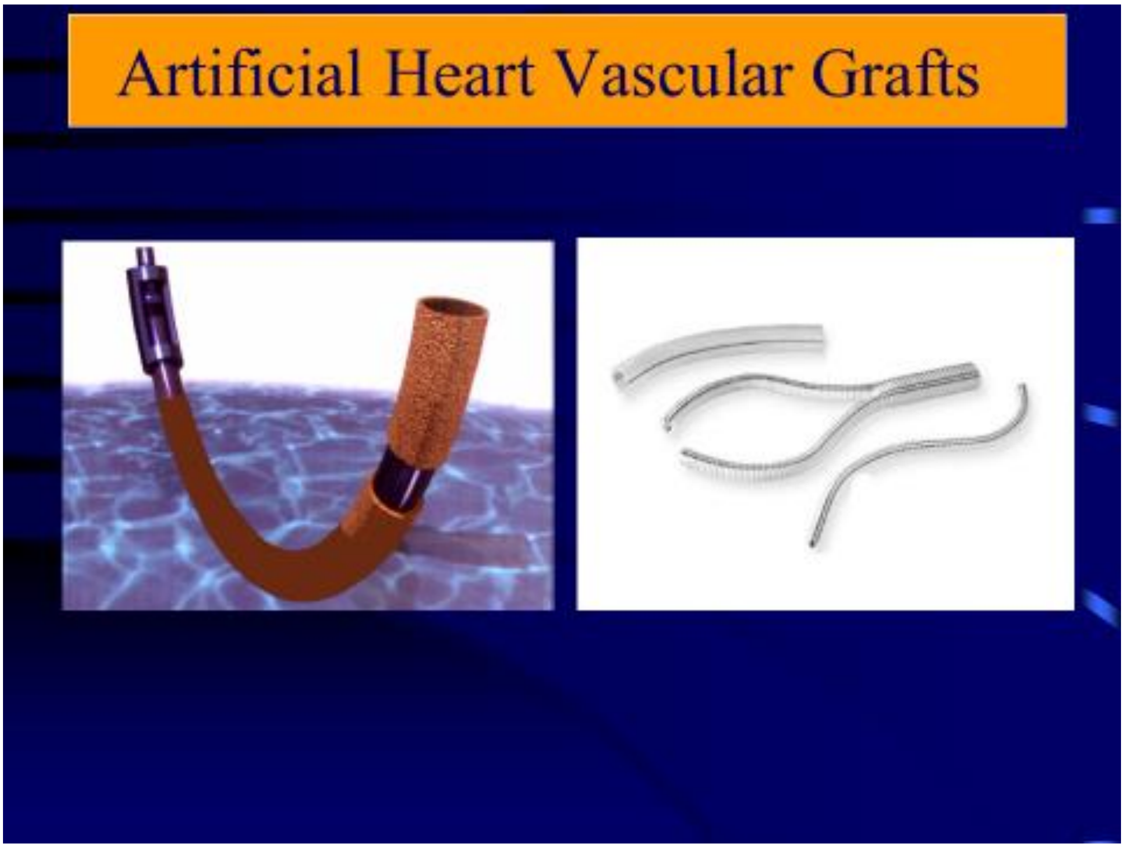
Cartilage Treatment



Cages for Spinal



Catheter and Stents



Artificial Heart Vascular Grafts