Biomaterials for spare parts

Your body is an amazing structure that can perform a wide range of different tasks. However, when tissues or organs of the body are damaged, your self-repair mechanisms are not always able to restore them to full working order. If parts of your body are lost through injury, then they do not usually grow back.

Early attempts at developing materials to place inside the body were usually unsuccessful—if patients were lucky enough to survive the operation they would often die from toxic effects of the implanted material, or from the body's reaction to the implant.

As we have come to understand more about the physics and chemistry of materials, and also how body systems work, it has become easier to repair, replace or improve various body parts.

Research into bionics has led to the creation of implants made from polymers, metals and ceramics that are well tolerated by the body. Biomaterials are synthesised from commercially available materials or purified from naturally occurring substances like coral.

Over time, materials have been developed to make implants that are more effective and less toxic. By the 1940s, materials were in use that resisted degradation in the body (that is, they didn't easily break down). Examples included high purity stainless steel, nickel alloys, tantalum, titanium alloys and silicone rubber. In the twenty-first century, many body tissues can be replaced by a wide variety of polymers, ceramics, metals and composites.

Metals

Many common metals and metal alloys have been used to make artificial limbs and devices to aid bone-setting. For example, iron, steel, gold, silver, copper, lead, zinc, nickel, aluminium, magnesium, titanium and various alloys have all been used to aid bone healing and function. But it was discovered that only a few of these metals and alloys, such as gold and titanium, could be tolerated well by the body. Some of the metals used, such as lead, were very toxic.

Three important alloys used in biomaterials today are titanium alloys, iron alloys and cobalt alloys.

Titanium is used for replacement hip joints, bone screws, knee joints, bone plates and dental implants. Titanium is biocompatible and is relatively unreactive. It is strong and easy to mould or shape. Unfortunately, titanium wears out easily.

Stainless steel is an iron alloy containing chromium, molybdenum and nickel. It is strong, easily worked and cheap to manufacture, but has a tendency to corrode (rust). It has about the same tensile strength as titanium alloys (960 MPa) but is denser—7.8 g/cm^3 compared with 4.5 g/cm^3 for titanium alloys.

Cobalt alloys are more expensive than stainless steel, but more resistant to corrosion. Cobalt–chromium alloys are often used as part of a hip replacement.

Ceramics

China plates and cups, clay pots, and roof and bathroom tiles are common uses of ceramics. Ceramics are also important biomaterials because they are strong, non-flexible, resist corrosion and have low density. They can be easily shaped when wet, but when they are heated strongly they become permanently rigid. They are used in dentistry as crowns for teeth and to make false teeth. They are also used for joint and bone segment replacement and temporary bone repair devices. As they are biocompatible, ceramics may be used as coatings for implants made of other materials that are less compatible with the human body.

Some types of glass and ceramics will form a strong chemical bond with living bone. These materials are said to be bioactive. Reactions between the glass or ceramic implant and surrounding body fluids cause a biologically active layer to form. This results in strong bonding between the implant and bone.

However, bioactive glass is often not suitable to use in implants where load-bearing is needed as it cracks relatively easily. There are stronger ceramic materials that are not as bioactive, but whose bioactivity can be increased by altering the surface.

Plastics

Amazing advances in bionic medicine have occurred following the discovery of how to make synthetic polymers. Scientists can now create 'designer plastics' with very different properties for almost any application.

Synthetic polymers that are used to repair and enhance the human body include polyurethane, polypropylene and nylon. When choosing a polymer to be used in the human body scientists need to consider its mechanical properties—whether it is brittle or bends easily, whether it stretches and how strong it is. They also need to consider how it will perform at body temperature (37°C), how tissues will react to it and how easy it is to make. Cost also must be taken into account.

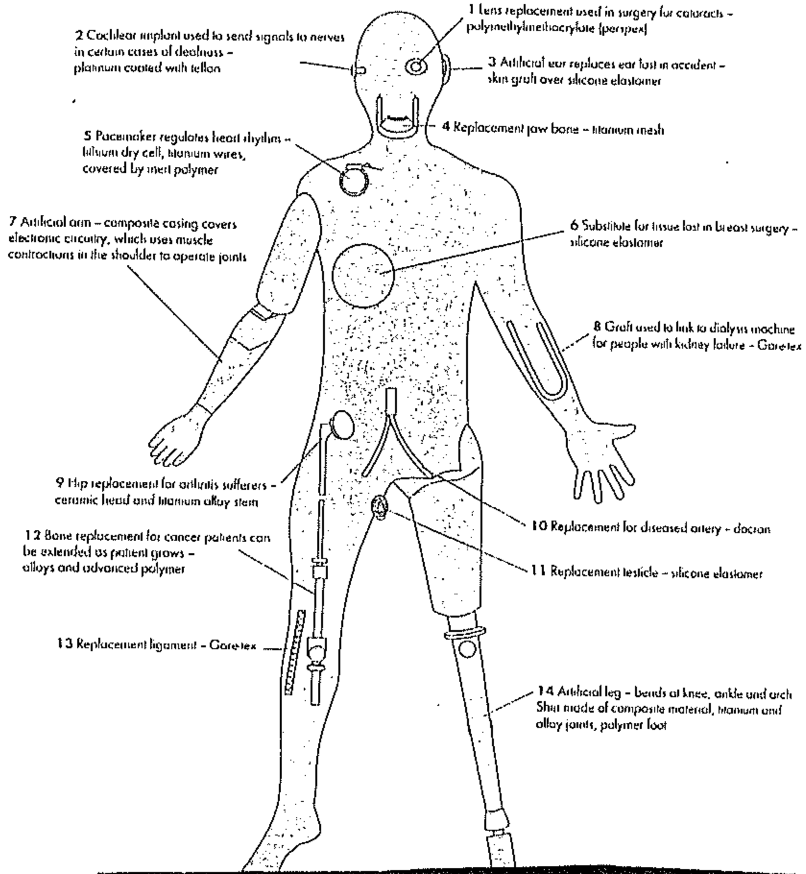
Polyethylene

Polyethylene is one of the most useful plastics—it is used to make an enormous number of plastic items such as plastic bags, children's toys and shampoo bottles. Polyethylene can be a linear or a branched molecule. Linear polyethylene can be made with molecular weights of three to six million and is then called ultra-high molecular weight polyethylene, or UHMWPE. This can be used to make very strong fibres (tensile strength 17 MPa) that are used in bullet-proof vests. It is used medically in making replacement joints such as hips and knees. UHMWPE is denser than normal polyethylene, having a density of 0.95 g/cm^3.

Like metals, UHMWPE is resistant to abrasion and cutting, and is also impact and corrosion resistant. It is self-lubricating and slippery—in fact, large sheets of UHMWPE can be used to make skating rinks. A disadvantage is that UHMWPE fibres tend to stretch under loads. Processing conditions, sterilisation method and age can all affect its performance. (See Section 2.3, p. 90 for more about the use of UHMPWE.)

Silicones

Silicones (polymers containing the element silicon) can exist as oily liquids or as rubber-like substances. You can buy silicone sealants at hardware stores for use in sticking tiles onto walls and floors. Silicone rubbers are very stable to many chemical reactants and to heat. Silicone is not damaged by ozone or ultraviolet (UV) light, or by the radiation used to sterilise medical equipment. It also has a very long life span—several hundred years. A common use of silicones is in breast implants, to restore the shape of breasts after surgery or to make breasts look larger, and to replace cartilage in small joints (see section 2.3). Silicone gel can also be used in padded bras. Silicones are used in heat-resistant seals and electrical insulators.



Polymer	Use
Polymethylmethacrylate (PMMA) (Perspex)	bone cement, contact lenses, dentistry
Polytetrafluoroethylene (PTFE) (Teflon)	artificial blood vessels and heart valves
Polyurethane	facial prostheses
Polyvinylchloride (PVC)	blood vessels, heart components
Polydimethylsiloxane (PDMS)	heart components, bones, joints
Polyesters	knee replacements
Nylons	joints, blood vessels, kidney dialysis
Polyethylene—ultrahigh molecular weight polyethylene (UHMWPE)	hip and knee replacements
Polysiloxane (silicone)	breast implants, finger joints