Medicine and Materials

- *UK researchers have pioneered the development of implants, artificial organs and tissue engineering – from artificial joints, corneas, bone and nerves to absorbable implants which can help the body heal and regrow its tissues*
- *Modern hip replacement surgery was invented in the UK*
- *The world's first permanent artificial heart was developed in the UK*

Boning up

When engineers, biologists and medical scientists first started to work together on the problems of biomedical science, a new era was born. The fruits of this 'bioengineering' were 'biomaterials'. Now, virtually everyone has a biomaterial of some sort in their body, whether it is a filling or a contact lens.

Many people also rely on more critical implants, such as artificial hips or knees. The first total hip replacement was in 1962 and used a plastic cup to replace the arthritic hip socket and a metal 'ball' for the head of the thigh bone. A cement attached the cup to the patient's bone.

Today there are many different types and combinations of artificial ball and socket. Ceramic materials, such as alumina and zironia, are also used for both ball and socket, or used with a polymer socket. Work during the 1980s and 1990s helped to make plastics and ceramics tougher and longer-lasting. Metals are also used for other types of artificial joints. Research has helped develop metal balls and sockets made from cobalt alloys. With advances in metal machining techniques in the 1990s, these materials are now smoother and tougher than before. Another option for the future being investigated by research teams uses ceramic balls with metal sockets.

Surprisingly, glass-like materials have also been used successfully as bone implants, particularly for middle-ear prostheses and to save decaying teeth. Long-term adhesion was a problem with other materials until Bioglass® was developed in the 1960s. This was the first man-made material to bond to living tissue in a single attempt. Because it releases small amounts of soluble silica and calcium, it activates seven families of genes present in bone cells, causing them to create new, healthy bone. The more recent discovery that powdered Bioglass® can induce bone to regenerate faster than its natural rate has opened up a wealth of new research opportunities. Now researchers are working on the use of Bioglass® to activate cells in tissues to repair themselves, investigating whether the body could regrow tissues such as cartilage.

Artificial bone is also used in bone grafts or repairs. Work by researchers in the 1990s, produced a porous material made from hydroxyapatite, the mineral which makes up almost three-quarters of natural bone, and polyethylene. Implants made of this composite bond naturally to bone without requiring cement. These materials are full of holes like a sponge, allowing blood to flow through, and natural bone tissue to grow in and around the holes. This is a great advantage over metal or plastic materials, which are hard all the way through. It's now used as a bone graft in a range of medical and dental applications.

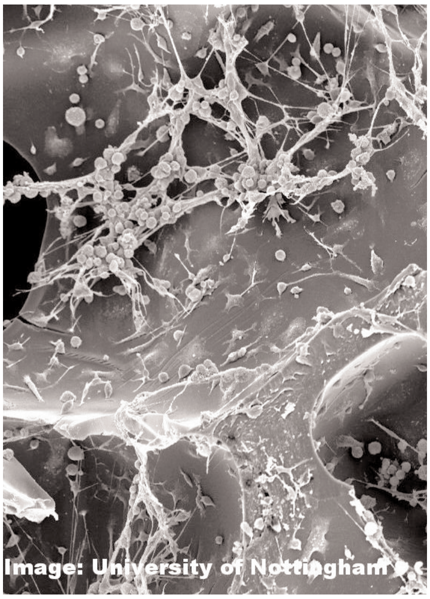
For the future, researchers are hoping to come up with implants that the body can completely absorb. For example, a biodegradeable polymer-based material that can be injected into the body without surgery is being designed. Once inside the body, the material transforms itself into an open-pored, three-dimensional scaffold like a sponge. It gradually releases a growth factor to encourage cells and tissues to grow around the scaffold. Eventually, the polymer scaffold disappears completely.

Soft stuff

Tissue engineering could be used to grow not just bone, but a range of tissues including ligaments, cartilage, skin or liver tissue. At present, there are a few tissue-engineered artificial skin products on the market. Cells taken from the patient are grown either onto bovine collagen, the substance that makes skin strong and resilient, or a biodegradeable polymer scaffold. When applied to chronic wounds, burns or ulcers, they encourage the body's own skin to regrow.

Another option is to use the patient's own skin cells. The advantage of these products is that they can survive permanently as well as kick-starting regrowth of new cells over the wound, whereas products based on donor cells can only be temporary fixes. Celltran, a small business spun out of the University of Sheffield, markets a product called *Myskin* that uses cells taken from the patient. These cells are delivered on to non-healing wounds or extensive burns on the back of a specially coated polymer dressing. Once the cells have moved off the dressing on to the wound, the dressing is discarded. Researchers are now working on biodegradeable three-dimensional polymer scaffolds, which will deliver patients' skin cells for use in reconstructive surgery.

Some tissues are easier to regrow than others. Nerve tissue found in arms and legs - peripheral nerves – will regenerate naturally if severed after an accident, but only exceedingly slowly. Without treatment, the nerve ends can form a useless, tangled mass. One answer is nerve guides, or conduits, which help peripheral nerves to regrow while guiding them in the right direction. An absorbable nerve conduit made from bovine collagen is already on the market, while a polymer version, being developed by UK university researchers, is in clinical trials in Europe. This graft consists of a biodegradeable polymer compressed to form a mat about as thick as the tissue in a kitchen roll, and then shaped into a tube. The tube is inserted where the nerves have been cut. The polymer fibres act like tracks allowing nerve cells to regrow faster inside the tube. Researchers are also working on a full artificial nerve that would temporarily replace a piece of nerve that has been lost until it can regrow again.



Human stellate cells growing on a 3D porous scaffold

On the horizon are implants that serve as artificial organs. For example, researchers are developing materials for miniature glucose sensors, which, when used with an insulin pump, could become an artificial pancreas. Meanwhile, other researchers have developed contact lenses that can monitor sugar levels in diabetics. Researchers are also exploiting advances in electronics by designing artificial retinas made from arrays of microelectrodes that could partly restore lost vision. The world's first artificial cornea is also being developed. Electronic circuits are also under development to restore the senses of smell and taste. If the burgeoning field of tissue engineering lives up to its promise, one day whole organs could be manufactured to replace those that are injured or diseased. Researchers are, for example, working towards making blood vessels, and even whole hearts, using tissue engineering.

Get pumping

However, for patients with heart problems, bioengineers are turning to completely different solutions, using all their expertise in metals, plastics and electronics. Perhaps the most exciting of these is the artificial heart. In June 2000, at the Radcliffe Hospital, Oxford, the world's first permanent artificial heart, made from aluminium, Dacron polyester and plastic was implanted. Researchers have shown that these devices help diseased hearts recover by allowing them to rest completely. The thumb-sized rotary pump fits into the left side of the heart where it moves with the heart as it beats. Before this, the pumps were so large they could only be left inside a patient for a few months. The research team devised a way to transfer power from a battery worn on the patient's belt without wires passing through the patient's skin, so reducing the risk of infection. Five and a half years later, the patient is still doing well.

On the horizon

The innovativeness of engineers, doctors and biomedical researchers has clearly improved our quality of life and prolonged our lives. Their expertise is improving the design of artificial organs and implants every year. Research continues to try to find substitutes for almost every organ and tissue in the body.

There is the hope that one day, whole organs could be manufactured to replace those that are injured or diseased if the burgeoning field of tissue engineering lives up to its promise. The science fiction of today could be a reality in our future.

Biomaterials timeline

1952: An artificial heart was used for the first time and kept the patient alive for 80 minutes.

1962: Sir John Charnley, Manchester, invented the modern form of hip replacement surgery.

1969: First man-made material to bond to living tissues, later called Bioglass®, was invented by Larry Hench.

1974: First implant of the prototype for modern total knee replacements.

1981: First artificial skin transplanted.

1982: First permanently implantable artificial heart designed.

1992: First synthetic bone implant made from calcium phosphate approved.

1998: First living tissue commercialised - an artificial skin to treat leg ulcers.

2000: Stephen Westaby, Oxford, fitted the first permanent artificial heart.

2001: First nerve guide (conduit), an absorbable implant to repair severed peripheral nerves, commercialised.

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