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Joint replacement

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Introduction

Artificial joints, particularly for the hip and knee, have been implanted successfully for over 40 years and are generally considered to be highly successful treatments, with about a million hips and knees are implanted every year worldwide. Several international companies in the field have manufacturing and research bases in the UK or Ireland. They include DePuy, Biomet, Corin, Stryker, Smith and Nephew, and Finsbury.

There are two fundamental approaches to restoring hip joint function using artificial joints. One is a total hip replacement and the other is hip resurfacing. This paper examines current and possible future systems.

The technology

In total hip replacement, the femoral head - the ball at the top of the thigh bone, and the acetabulum - the socket in the pelvis, are both replaced using artificial materials. The femoral component is usually held in place by a metallic stem which sits inside a surgically enlarged medullary cavity (the hole down the centre of the femur). It is either cemented in place using a surgical cement made from polymethyl methacrylate (Perspex) or is textured and coated with the mineral found in bone (hydroxyapatite, HA) to allow the bone to grow into the texture and secure the implant. The stem is usually made of metal such as stainless steel, cobalt chromium molybdenum alloy (CoCrMo) or titanium. However the ball that rubs against the acetabular component is never made from titanium as it is too soft and wears quickly even when rubbing against a plastic. Usually the ball is CoCrMo or a ceramic material, mainly alumina or increasingly a zirconia toughened alumina.

The acetabular component, which rubs on the femoral head component, is made from ultra high molecular weight polyethylene (UHMWPE), cross linked polyethylene (XLPE), ceramic or CoCrMo, though there are some new materials undergoing research. Again these components are either cemented in place or are coated and use bone on-growth to secure them.

Components are often modular so that different combinations of head and socket can be used. Modular femoral devices consist of a stem which is fixed into the bone with a conical section at the top on to which different types of head are fitted. In the case of the acetabulum, modular components are also fixed into the bone and then the bearing surface is fixed into the modular backing cup. This means that while using the same components attached to the bone, the sliding surfaces can be changed to suit the situation.

Depending on the type of joint, costs vary from approximately £1,000 to £3,000 for the joint itself with the whole procedure (surgery, hospitalisation and joint) averaging £6,500 per joint replacement. A metal on metal hip resurfacing carried out privately by a leading surgeon generally costs more than £9,000. The National Health Service budget provides funding for joint replacement, as it represents value for money with patients often returning to independent living, saving high costs in the long term.

The important issues

Cemented joints have the advantage that within 24 hours of the operation, the cement is at full strength and so the patient can safely walk on the hip. The disadvantage is that if for any reason the joint needs to be removed, it is less easy to remove the cement from the bone, though this is done routinely when necessary. Bone in-growth into the porous layer (where the bone grows into pores in the artificial joint) tends to be considered for younger patients where modular devices are used, so it is expected that the stem and acetabular socket may not need to be removed; only the femoral ball and the acetabular liner will need to be changed. Full strength will only be achieved once the bone has grown into the roughened surfaces of the modular components.

It is very rare that components break. Experience at designing these has almost eliminated direct fracture of the components. The main cause of failure is called "aseptic loosening" which means that the joint components come loose within the bone. There are two main causes of this.

One is that the artificial joint is so much stiffer than the bone that the normal pattern of stresses within the bone is disrupted, and some parts of the femur or pelvis experience low stresses because the loads are being transmitted through the stiffer artificial joint material. This is called "stress shielding" and leads to bone being resorbed (lost) on the basis that if the body has tissues which are not being used then there is no point maintaining them. So bone is not regenerated and the joint comes loose and becomes painful.

The other reason for loosening is a biological reaction to wear debris in the form of very small particles of material worn from the artificial joints. Cells called macrophages have the task to clear up material that is not required in the body. However many of the materials used in artificial joints are very inert and so the cells fail to remove the tissue but in their attempt to do so they remove bone tissue which is surrounding the wear debris. This again causes joints to become loose and consequently painful.

In a recent study, over three-quarters of metal on UHMWPE artificial joints were seen to be still working after 25 years. However this does depend on what the patients do with their joints. To get the best life out of metal-on-plastic joints, the head diameter needs to be small, as this has been shown to give lower wear. However if the recipient of the joint wants to do more athletic activities, then the joints wear in direct proportion to the amount and severity of the usage. Also if the joint diameter is small, athletic activity may cause dislocation of the head from the socket. To prevent this, larger diameters are necessary but this leads to greater wear rates. Hence different materials have to be considered. Metal-on-metal joints are harder but in small diameters have been shown to exhibit high friction. In larger diameters though, they generate a film of body lubricant (synovial fluid) between the two rubbing surfaces, which reduces the friction and reduces the wear because the two surfaces do not touch as they are separated by a very thin film of lubricant.

A requirement for large femoral heads leads to hip resurfacing. In this case rather than remove large amounts of bone, the metal components are thin layers that simply line the bone. There is no long stem in the femur, and the bone of the natural femoral neck, as well a substantial part of the head, is retained. These operations have proved very effective in more active patients but some people are worried because these joints produce very small metallic particles from which metallic ions are produced and pass around the body. Metal on metal joints have been implanted in people for over 30 years with no evidence that these ions have caused major problems, but nevertheless sufficient concern has been generated that the popularity of this procedure is starting to be affected.

Future work

By cross-linking the UHMWPE acetabular components, wear rates can be reduced by up to 75 percent in hip joints, potentially leading to longer-life hip replacements. However, by cross-linking the polyethylene the wear debris causes more biological reaction so the full 75 percent advantage is not likely to be obtained. These joints have only been used for about 10 years in clinical practice though, so their true long-term performance is still unknown.

To avoid the levels of metal ions found in the body when using metal-on-metal hip resurfacings, ceramic heads have been paired with metal cups (CoCrMo). This roughly halves the level of metal ions though it does not eliminate them totally.

The other concern about metal components is that metals are very much stiffer than bone, so that stress shielding can be a problem. Experiments have been carried out combining ceramic heads with softer polymers such as carbon-fibre reinforced polyetheretherketone (CFR-PEEK) with remarkable results. The wear rates are only one hundredth of UHMWPE, which is even better than XLPE, and early reactivity results are encouraging. The disadvantage is that the friction is quite high, but work is going on to address this.

Another new idea is to mimic the natural joint by using an elastomeric material of similar modulus to cartilage which is the body's own joint material. So far, polycarbonate urethane (PCU), in a well-designed joint, has been shown to be effective in this role with extraordinarily low coefficients of friction, lower than human joints, when running against ceramic femoral heads. This low friction is caused by the fact that PCU produces fluid-film lubrication just like natural cartilage and thus the surfaces are completely separated by the body's lubricant. Naturally this also leads to low wear. Preliminary experiments also show that PCU wear debris is not very reactive in the body.

The best solution would be to replace our worn-out cartilage with re-grown or tissue engineered cartilage. This showed great promise some 10 years ago when small cartilage lesions were re-grown. Although extending this to whole joints has proved problematic, research is still going on in this direction.

Conclusion

Many of the original ideas for artificial joints have originated in the UK and many are made in the UK, albeit by companies which may not always have UK owners. Many of the metal-on-plastic materials for hips are also applicable to knees, including the CFR-PEEK and the PCU combinations. Knee designs still rely heavily on CoCrMo femoral components and UHMWPE tibial (shin bone) components and their designs have improved greatly in recent years. Long term usage is now becoming a strong reality.

Many joints, other than hips and knees, are regularly replaced, including, fingers, toes, wrists, elbows, shoulders and even spinal sections and in these cases different materials are sometimes more appropriate than those discussed here. However the whole area of joint replacement is still ripe for further improvement in spite of the major developments that have occurred so far. In particular the materials now need to be more sympathetic to the body in terms of material properties and compatibility and these are areas that are being actively pursued both in academia and in UK industry.

Author: Professor Anthony Unsworth FREng, Director, Centre for Biomedical Engineering, Durham University

Contact

For more information please contact:

Katherine MacGregor
Policy Advisor
The Royal Academy of Engineering
Tel: 0207 766 0623

katherine.macgregor@raeng.org.uk