Human mobility – benefits and limitations of total joint replacement in the hip and knee

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Author's Profile

Professor Volkmar Jansson enrolled in Mechanical Engineering at the University of Hannover and graduated in 1980 with honours. During his engineering studies he already began to study medicine with the goal to integrate his technical and biomechanical ideas into the practice of medicine. Several traveling fellowships took him to the Royal College of Ireland in Dublin, the University of Southern California in San Diego and Duke University in North Carolina. He undertook his specialty training in Orthopaedics at the University of Munich, were he also became an academic lecturer. As a consequence of his engineering background, Professor Jansson's specialties are the development of hip and knee replacements as well as biological research with the goal to generate cartilage from stem cells. For his work in these fields, he has received numerous awards. In 2001, Professor Jansson became chairman of the Orthopaedic Department at the University of Rostock, from where he returned to Munich in October of 2003 in order to assume his current position.

Introduction

According to the World Health Organisation, obesity has become a global disease in humans with widespread consequences concerning general health, increased risk of cardiac and pulmonary complications and orthopaedic problems. A high weight load not only destroys cartilage but it also leads to degenerative arthritis. In addition, even in joint replacement, wear problems of the articulating surfaces are related to bodyweight. Therefore, nutrition and physical fitness are crucial factors for the success of total joint replacement in humans.

Total hip replacement

Both total hip replacement (THR), and total knee replacement, are safe and standard procedures in humans. THR are performed more than one hundred and eighty thousand times a year in Germany alone. A major breakthrough in THR was in 1959 when Sir John Charnley introduced bone cement for interlocking the endoprostheses. However, despite many efforts the main problem, the aseptic loosening of the implants, is still unresolved. However, some of the major issues of THR can be addressed:

Tribology: Wear problems are of great concern (fig 1). Debris such as polyethylene or metal particles can trigger immunologic reactions that finally leads to bone resorption and loosening. The problem is addressed as 'polyethylene disease' and was first described by Willert. In man five hundred thousand polyethylene debris particles are released during each single step! This problem in particular is strongly related to bodyweight.

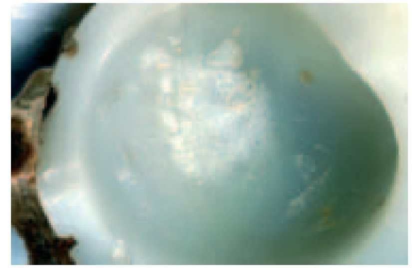

Figure. 1 Polyethylene cup showing severe signs of wear such as delamination.

To replace the rather soft material polyethylene, other ('hard') materials are used to improve wear problems. The introduction of the new ceramic-to-ceramic articulation seems to be promising as long as no impingement between cup and neck occurs. However, in cases of impingement, breaking of the implant is likely with all its devastating consequences. To overcome these mechanical problems, metal-to-metal articulation has gained new importance over the past years. Metal-to-metal articulation was first used with good results in McKee Ferrat endoprostheses. However, metal debris still occurs even if special alloys are used alongside optimised movement of the articulating surfaces. The metal debris can lead to their high concentration in serum which could have negative effects on kidney function and might act as a carcinogenic agent.

New cementing techniques: As the mechanical strength of bone cement is rather low, improvements in cementation of implants have concentrated on cementing techniques.

Figure. 2 Stem used in total hip replacement for 'secondary cementation technique'. Cement is injected through holes after the stem is inserted into the femoral canal.

The aim is to avoid further weakening of the cement layer due to blood lamination or air bubbles. Recently, new cementing techniques have been introduced for stem (femoral head component) cementation. These techniques reverse the cementing procedure. In this technique the stem is introduced into the femoral canal first, then (secondly) the cement is injected through holes within the implant (fig 2). According to the procedure the process is called 'secondary cementation technique'.

Both the position of the implant within the cement mantle, as well as the penetration depth of the cement into the cancellous bone, can be perfectly controlled by this method. Using Finite Element Method analysis (FEM – a computer-based method for the design, mechanical stress analysis and fabrication of prosthesis structures) it can be shown that a 2-3mm cement penetration depth leads to optimal results in terms of mechanical stability and preserving bone stock (mass). By adapting the cement pressure during cement injection this cement penetration depth can be achieved.

Cementless fixation: For cementless fixation, coatings like hydroxyapatite (HA), or porous titanium plasma spray, have improved the interlock and ingrowths of bone. New coatings using biologic active substances seem to be possible and might further improve implant fixation.

Figure. 3 "Wagner cup" for total hip replacement. Cemented acetabular (polyethylene) and femoral (cobalt/chrome-alloy) cup.

"Small implants": Neck preserving implants like femoral cups and short stems seem to improve bone stock condition in cases of an exchange operation (a revision operation with complete replacement of the original implants) (fig 3). However, the mechanical load transfer mechanisms of short stems are rather intricate, thus the rate of aseptic loosening is high with such endoprothesis. Nevertheless, small implants seem to be challenging and future developments will concentrate on this field.

"Small incisions": Minimal or less invasive methods of THR seem to be promising in terms of muscle trauma, blood loss and rehabilitation. Several anatomical approaches are possible, some, but not all of them, seem to be promising. In all cases, small incisions require experienced surgeons, since visualisation of the operation site is limited. For this problem, computer assisted navigation techniques might be a useful tool in the future.

Total knee replacement

In total knee replacement, major improvements were achieved with unicondylar joint replacement (where only the lateral or medial aspect of the knee is replaced). Especially with the mobile bearing concept (the polyethylene implant on the proximal tibial tray is not fixed but is 'free floating' in its contact with the implant), mobility and function are excellent after such a procedure. By applying minimally invasive operation techniques the intra-operative trauma can be minimised (fig 4).

Another achievement in total knee replacement are the computer assisted navigation techniques recently developed (fig 5). By means of these techniques the precision of implant positioning can be improved, thus leading to better kinematics (motion) and clinical results.

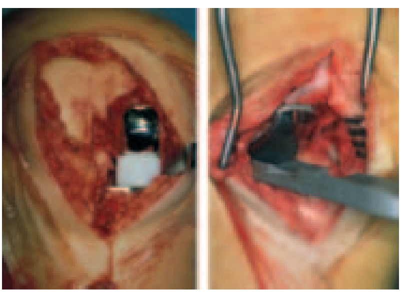

Figure. 4 Open (left) versus minimally invasive (right) technique in total knee replacement.

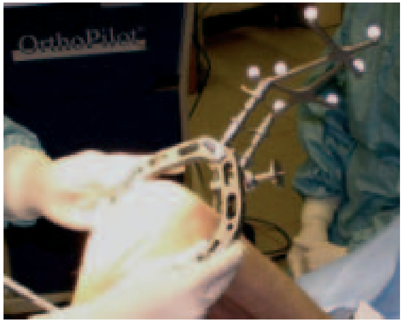

Figure. 5. Intraoperative positioning of drilling tool by means of computer assisted navigation.

Future developments and summary

Future developments will include so called bioimplants (fig 6). These implants act as a 'scaffold' and are made from biodegradable materials. By the time these materials degrade, bone and cartilage tissue have formed in these scaffolds. In the most common techniques, pre-cultured chondrocytes are seeded into such scaffolds and are also replaced into the defect of the joint by a second operation.

Further developments will concern improvements of materials to further reduce debris in articulating surfaces and the development of better fixation techniques for short stem fixation in total hip replacement.

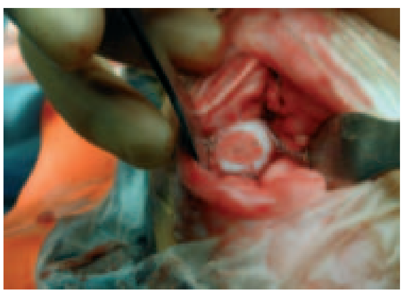

Figure. 6 Implantation of a bioimplant