Engineering in Medicine 2

Advances in Artificial Hip and Knee Joint Technology

Edited by

M. Schaldach and D. Hohmann

in Collaboration with

R. Thull and F. Hein

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FOREWORD

Implantable joint prostheses which have been under development for more than 25 years, are today being used with success in the rehabilitation of many cases, including patients with extremely severe joint pathology. However, artificial joint designs still pose problems with respect to their function, anchoring, materials employed and the interaction of the prosthesis with the surrounding biological tissues. Some of these problems are associated with considerable therapeutic complications.

Further improvement in the artificial joint requires the application of all the modern experimental and research techniques and the close cooperation of medical doctors, engineers and scientists. The International Symposium on Advances in Artificial Hip and Knee Joint Technology held at Erlangen on October 30 and 31, 1975 under the auspices of the Societas Physica Medica Erlangensis, had as its aim the promotion of just this interdisciplinary cooperation. One of the traditional objectives of the Societas has been the advancement of diagnosis and therapy by the adaptation of medical skill to modern technology and scientific engineering concepts.

The major objective of this volume is to present, in expanded form, the lectures given by internationally recognized scientists and clinical researchers in the field of artificial joints in the locomotor system, and to make that information available to a wider public. The experience discussed covers the principles and primary methods of joint replacement. Particular emphasis is on problems of pressing importance at the present time, such as improvement of the general design, the fixation systems and implantable materials for hip and knee joints, as well as the postoperative management of a steadily increasing number of patients.

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STATE OF THE ART OF HIP AND KNEE JOINT REPLACEMENT

G. Friedebold and R. Kölbel

A dream seemed to come true when George McKee's first patient with an artificial hip joint took his first steps, was able to move, sit and walk painlessly and unobtrusively. Payr, one of the fathers of joint surgery had hoped to realize this dream conceived 150 years ago: Restoration of the ruin of a joint with its pain, contracture or instability. The optimism of this great surgeon, expressed in 1934 was based on the results of conventional interposition arthroplasties improved by Lexer himself and are followed up and reported sporadically (4). It was not until 30 years later that the resolution of some of the problems by positive fixation of artificial joint components by Charnley (5) opened up a new epoch of joint surgery.

Ten years have since passed; partial arthroplasties were introduced or interposition arthroplasties with a metal cup (21,27,40,48). Articulations of one artificial articular component on its biological counterpart is basically different from total joint replacement in that a body of low compliance is pressed against cartilage and bone, and in that the interaction of cartilage surfaces and synovia is disturbed both in static and dynamic loading and shearing relative movements. For a method whose objective it is to obtain lasting and normal function of an artificial organ, 10 years is not a very long period of time for assessment. Even for patients over 65 years, 10 years experience does not permit us to promise lifelong service since life expectancy may be well over 75 years.

Excellent early results have contributed to an optimism among patients and surgeons that is unprecedented for an operation which is not life-saving.

In the meantime complications and failures have been reported – only occasionally at first, but subsequently in ever increasing numbers. Thrombosis and early infection are mentioned because of their general surgical importance and due to the fact that, in contrast to some other surgical procedures, infection is fatal for the outcome of the arthroplasty.

The incidence of periarticular calcifications, an occasional finding, may be influenced by operative technique. Attempts at local or systemic drug application to prevent calcifications have not been satisfactory. Their clinical significance is doubtful as they are not always associated with compromised motion (16).

Loosening with or without infection is the most important cause of failure. In patients with artificial joints which may have been functional for years, walking and movement become painful due to loosening, at a time when the results in these patients have long been listed as sucesses. Increasing incidence of failure within the ten-year-limit raises the question as to whether we can truly speak of a victory over the problems of arthroplasty, or, has the problem of arthroplasty really been solved in the spirit of our great teacher Payr?

Osteoarthritis, a chronic degenerative lesion of the joints caused by a number of etiologic factors arises as a consequence of a disturbed balance of the biological potential of the joint and the mechanical stress and strain. These are of paramount importance in the case of the lower limb; hence the large proportion of degenerative lesions of hip and knee joint. Endoprostheses have been designed for most of the peripheral joints. However, experience has not yet led to unequivocal conclusions. To sum up the results of arthroplasty of the last decade and the present state of the art one will have to look at the hip and knee, the replacement of which is of eminent practical significance.

There is a time lag in the development of implants: When Walldius (51), later Young (53), Shiers (45) and a few others reported on initial results after knee joint replacement, hip replacement had already spread like wildfire. While attempts to modify or improve McKee's and Charnley's models were in full swing, the followers of Walldius, Young and Shiers were still using their original designs – gaining experience and analysing it. Meanwhile, knee joint replacement has been advanced and today we are in a position to evaluate, not only a vast number of design models, but also an appropriate variety of such failures as loosening and late infection. There may still be a time lag as regards their appearance in statistics.

Before reviewing the problems as they present themselves, we shall first deal with some aspects of joint replacement in general and of hip and knee replacement in particular. Present-day solutions, as regards engineering and biological aspects, appear as powerful therapeutic media. Nevertheless the application should occur carefully, taking into account the conditions in the individual patient. Hence we shall finally dwell upon indications.

GENERAL ASPECTS OF JOINT REPLACEMENT AT THE HIP AND KNEE

In the lower extremity, both great joints are subjected to high static and dynamic loads. The general aspects we have to deal with apply equally and basically to both the hip and knee joints.

IMPLANT MATERIALS

Starting with the original designs of McKee and Farrar and Charnley the combinations of metal on metal and of metal on plastic have gained in popularity. With modified designs, these models are currently in use. Although the range of application is quite restricted for hemiarthroplasties, we still have to deal with the combination metal on cartilage. The recent application of ceramics seems to have opened up new perspectives. The application of materials of this type is now at the stage of clinical trial and will not be included in this review.

MATERIAL PROPERTIES

In contrast to temporary implants, higher mechanical strength is required of permanent implants, which are subjected to a greater number of load cycles (14). A combination of required properties in a single material will be achieved by alloying certain basic metals, however, the optimization of one specific property may mean less than optimal values for others. As yet, there is not ideal alloy and experimental research is still going on (42). At present, alloys of three basic metals are being used. Their properties are listed in Table 1.

Improvements will certainly be possible through cooperation between metallurgists and bioengineers familiar with mechanical loads on permanent implants, with the severe environment to which they are exposed in the body, and with the requirements of body compatibility of solid materials and their wear and corrosion products (11,13). After initial experience with Teflon and other polymers, high density polyethylene has been found to be the plastic material which meets most practical requirements. As a paraffin derivative it is chemically inert; even its wear particles produce little tissue reaction. No carcinogenic effect has been proven in man. Its tensile and bending strength properties exclude it as a sole material for use as fixation parts or to bridge defects. Since Charnley (8) demonstrated its properties as a bearing material in combination with metal surfaces of defined radii, the metal on plastic combination has become universal in a vast number of joint replacement implants for the hip and knee.

In the early stages, total joint replacements were designed for direct fixation to bone. Today we are witnessing a swing back of interest to this idea. But ever since the introduction of polymethylmethacrylate as a means of fixation, the majority of surgeons have used it. In the polymerized state this material has adequate compressive and shear strength, it is inert and non toxic. Hypersensitivities have been reported in surgeons but not in patients.

Table 1 Comparison of requirements and properties for the employment of metallic materials for artificial joints

	Steel	CoCrMo-Alloy Cast - Forged	Titanium TiAlV-Alloy
1. High static strength, low modulus of elasticity	+	++	++
2. High fatigue strength	++	+ +++	+++
3. Max. corrosion resistance under intracorporeal conditions	+	++	+++
4. Body compatibility for implant and wear particles	+	+++	+++
5. Workability	+++	+	++
6. Low cost	++	+	+

CHARACTERISTICS OF MATERIALS AS ARTICULATING SURFACES

Loading and articulation at normal joints are fairly slow dynamic actions. Biologic materials and designs are perfectly adapted to them. The changes we impose on this balance by different types of alloarthroplasties have to be considered:

In hemialloarthroplasty a metallic body articulates with hyaline cartilage. We realize today the importance of the change in the lubricating mechanism and the stress distribution which this means and which may over different periods of use lead to replacement by fibrocartilage or removal of hyaline cartilage and erosion of the underlying bone (Fig. 1). In the case of optimal matching of the surfaces, moderate loading and solid subchondral bone cobalt-chrome-molybdenum femoral head replacements of the Moore (29), Thompson (50) or Eicher (12) types may well serve their purpose. Their use, however, is restricted to subcapital fractures of the femur and their sequelae in the very old.

In the knee McIntosh's (25) replacement of the tibial plateaus is still in use in certain (posttraumatic) conditions (Fig. 2). Surface replacement of the femoral condyles has had some good results as regards mobility, but load-bearing may be painful.

Apparently the tibial articular surfaces are softer than the femoral condyles which seem well able to support the friction and pressure by a McIntosh plateau made of a cobalt-chrome-alloy. Again, good matching of the surfaces is a prerequisite of success.

METAL ON METAL JOINTS

The classical metal on metal joint, made of cast cobalt-chrome molybdenum-alloy, has been followed by the Stanmore metal-to-metal hip, the Ring prosthesis (41) and Sivash's metal-to-metal hip (47) which was at the time made of titanium. They each have a great number of supporters to this day. For electrochemical reasons, the use of identical metals for the articulating surfaces is obligatory. Their geometry is of critical importance: Maintenance of a passivated surface layer may be of relative importance for the service life of the articulating surfaces. This may be destroyed by excessive pressures i.e. mismatch-

Fig. 1 Erosion of the hyaline cartilage of the hip socket in hemialloarthroplasty. Shifting of the head of a Moore prosthesis towards the small pelvis