A healthy human hip joint functions with minimal friction: optimal lubrication keeps the heavily stressed surfaces of both femoral head and acetabulum completely apart. In spite of high stress they show almost no wear. In arthritis, however, lubrication decreases, leading to friction and wear of the joint surfaces. Intense pain is the result. Painless movement of the hip joint can thus only be restored by implanting a prosthesis. But in an artificial joint the various movements and the forces to be transmitted preclude a homogeneous lubricating film between the load carrying surfaces. Parts of the surfaces come into direct contact, so that friction and wear are unavoidable – a fact unchanged by any of the materials and measures available today for modification of the ball and socket surfaces. With Metasul (Fig. 1), Sulzer Medica has developed a joint system that sharply reduces wear. Carefully conducted examinations on explanted hip joints, comparisons of various material pairs on a hip simulator and ten years’ experience confirm this fact.

**TWO WEAR MECHANISMS**

The wear process in an artificial hip joint is a complex process that can only be observed indirectly, by means of its effect on the surfaces involved. There are two main categories of wear:

- Wear due to adhesion: surface structures stick together, with resulting local solid-state welding, so that material is transferred from one surface to the other.
Wear due to abrasion: tiny hard surface particles break off and become abrasive particles (compare box).

In order to keep the adhesive wear at a low level, the sliding surfaces should be as hard as possible. Soft materials have a greater tendency to stick to one another. For the prevention of abrasive wear, on the other hand, the higher the fracture toughness of the surfaces, that is the greater the resistance to microfractures, the less pronounced is the abrasive wear. Ceramic materials are very hard, but are brittle and therefore not fracture-resistant. Fracture toughness is a typical characteristic of metallic materials, but these are relatively soft. Therefore, resistance to both adhesive and abrasive wears must be found in an alloy.

### High Precision Essential

In 1951, the surgeon George Kenneth McKee decided to have his all-metal hip prosthesis produced from a carbide containing CoCrMo cast alloy. Both McKee and all the other pioneers who designed hip prostheses with metallic pairs in the 60s and 70s remained true to this type of alloy. As early as 1900, Elwood Haynes had developed this type of alloy based on cobalt with embedded carbides. Carbides are chemical compounds of carbon and a metal and are created when an alloy is melted. They have the characteristics of ceramics, great hardness for example. They are therefore useful for protecting sliding surfaces from adhesive wear, while the fracture...
Photomicrograph of abrasive scratches on a Metasul joint component. These scratches are gradually polished away by the relative motions of ball and socket (arrow).

EXCELLENT RESULTS WITH METASUL

At present, about twenty CoCrMo alloy types have been developed, the best known of these being Haynes Stellite 21. Sulzer Medica gave to its own product the name Protasul-21WF. Protasul-21WF is a mixture of two components, the metallic matrix and the embedded chromium and molybdenum carbides (Fig. 2). As both components are formed in the melt, they are very tightly bound to one another, in spite of their quite different characteristics. This alloy differs from that used by McKee in that this one is forged. In the process of forging, the carbides are distributed more thoroughly in the metal matrix, which makes possible a homogeneous structure.

In comparative tribological experiments, metal-metal sliding surfaces made of Protasul-21WF showed the greatest resistance to wear of all the materials tested.

SURFACES POLISH EACH OTHER

The carbides protruding from the surface of the CoCrMo forged alloy are abraded more at the beginning. This leads at first to increased initial wear, which rapidly stabilises at a low level, however. The fracture toughness of the metal matrix and the polishing effect of the carbides thus act together to produce the desired smooth sliding surfaces. A high degree of security is thus assured, even in atypically severe stress, for example dislocation. The damage produced on the microscopic level in such a situation is polished away by articular movements (Fig. 3). This effect has been shown on all the metal-metal hip joint prostheses of both the older and new generations. The exact clearance between ball and socket is an essential prerequisite for a declining wear rate (Fig. 4).

THE RESULTS OF INTENSIVE INVESTIGATIONS

A total of 144 explanted all-metal hip joint prostheses were examined for in vivo wear. 30 of these consisted of Co-28Cr-6Mo-0.2C cast alloy and were produced between 1966 and 1970. Metasul
components of the forged alloy of the same composition had been used for the remaining 114 prostheses. The older type prostheses had been implanted for between 36 months and nearly 30 years, while the Metasul prostheses had been in place for between two months and more than eight years. For comparison with these explanted prostheses, new Metasul implants were subjected to extensive tests on a hip joint simulator that simulated the stresses and movements of an implanted joint. The joints were lubricated with a fluid that is very similar to the synovial fluid of human joints.

**Exact Measurements Realised**

The ball and socket components of all these implants were measured on a co-ordinated measuring machine with a resolution of less than 1 µm. Measurements were made every 7.5° on 12 concentric circles, which gave a total of 577 measurements per component. The location of highest wear was thus measured, an impossibility with the gravimetric method, which only indicates average values. Measurements of the components tested with the hip joint simulator were done before the test and then after 500 000 motion cycles each. In the running-in phase of about a million motion cycles – corresponding to approximately a year's implantation – the implants showed about 25 µm wear. Thereafter the wear sank to 4–10 µm per million motion cycles (Fig. 5).

**Measurements Agree**

The wear rate of the components tested on the simulator showed good agreement with that of the explanted prostheses (Fig. 4), although the rate is independent of the wear mechanism. After three years in situ, the linear wear rate per component was 2–5 µm. A comparison of the volumetric wear of the Metasul pairs with that of a polyethylene-ceramic or a polyethylene-metal pair shows values of 1 : 20 : 60.

Following the first implantation of the Metasul hip joint in the year 1988, more than 60 000 of these joints, 120 000 components altogether, have been produced.

**For More Details**

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4 Effect of various degrees of clearance on the test results of three joints with metal-metal pairs on the hip joint simulator: While joints 2 and 3 show the proper clearance, joint 1 is being tested with double the clearance.

5 Average yearly in vivo wear rate of Metasul hip joints and the standard deviation, measured after explantation: Wear decreases sharply after the running-in phase.