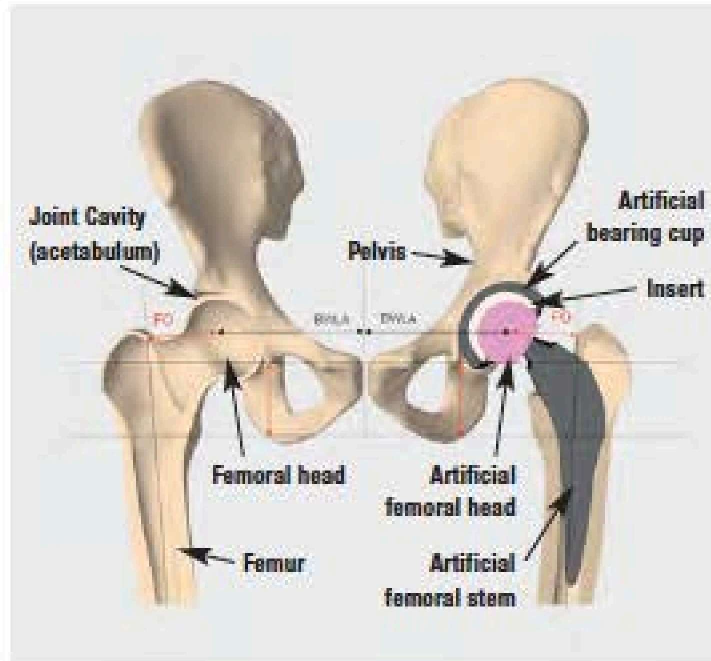
Jogging and jumping again with new joints

Prostheses improve the lives of millions of people young and old. The growing worldwide demand in the hip and knee prosthesis market is met by the development of increasingly reliable, robust and durable devices. Molybdenum plays an important role in the metallic materials used to make them.

Growing demand
Molybdenum is widely used in building construction because it gives hardness, strength, and corrosion resistance to structural materials, in particular alloy and stainless steels. It confers these same properties to the alloys used in human body reconstruction, as an alloying element in orthopaedic implants.

It is estimated that each year nearly 1.5 million hip and several hundred thousand knee replacements (arthroplasties) are performed throughout the world. The number of replacements is growing, driven by age-related causes like arthritis, and the growing needs of an active younger population, often sports enthusiasts, whose joints are worn by heavy exercise.

When joints are replaced, the prosthesis must remain in good condition for a long time to assure the patient's comfort and quality of life. Even normal daily activities (walking, standing, climbing stairs) impose significant stresses and frictional effects on the prostheses, which present a challenge to joint-replacement technologies.



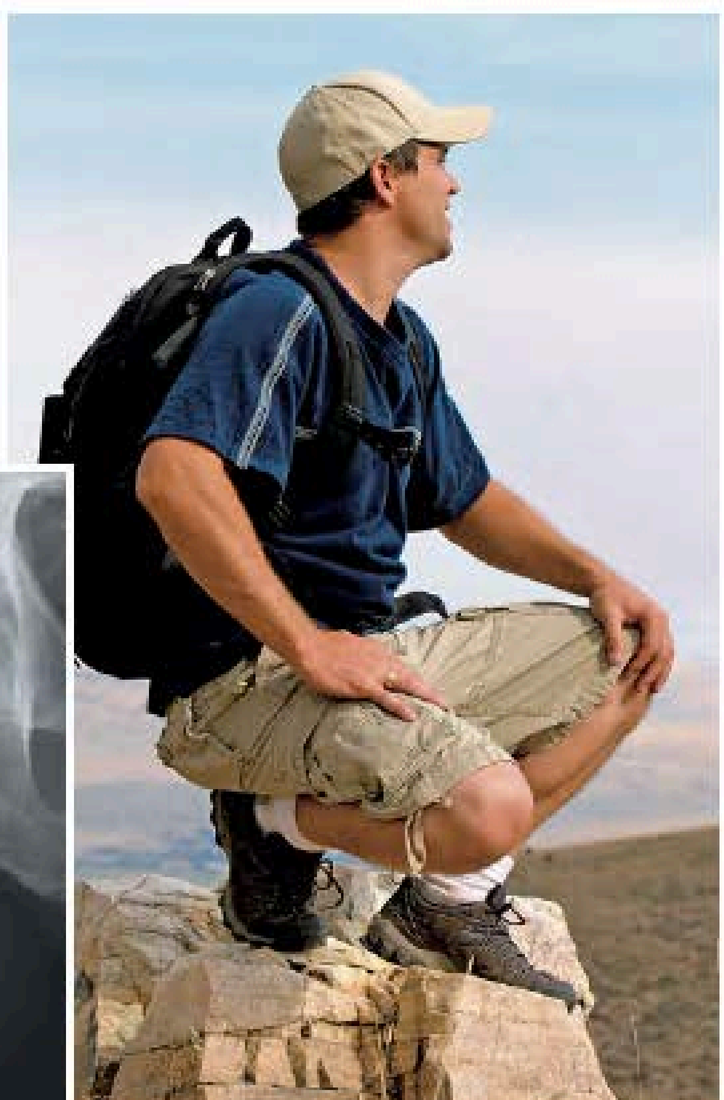
The hip: a ball and socket joint. Photo: Symbios.

The hip, a ball pivot as fragile as it is essential
The hip is the ball-and-socket joint formed by the femoral head at the upper end of the femur freely rotating in the cup-like cavity called the acetabulum at the edge (ilium) of the pelvis (see illustration).
A deficient hip undermines the body's dynamic and static balance and can be extremely painful. There are many possible causes for hip replacements: osteoarthritis (wear of the cartilage), necrosis of the femoral head (death of bone tissue due to temporary or permanent loss of blood supply to the femoral head), a rheumatic disease, a congenital (present at birth) malfunction, or the fracture of the neck of the femur, which cannot be repaired in a different way, especially in elderly people. In most of these cases a total hip replacement is the solution to the problem.

Total hip replacement means a complete replacement of the joint linking the femur to the pelvis with artificial components.

The anatomy of the cantilever-like femur presents a risk of breakage (the infamous femoral neck fracture) and requires a robust femoral stem design that can only be obtained by using metal, which is strong and tough. To attain a strong bond between the metallic femoral stem and the femur two techniques are used: One is to cement the stem in place, while the other is to apply a double coating, a coat of porous titanium followed by a coat of hydroxyapatite (a pure bone crystal comparable to coral), which stimulates bone cell growth into micro-pores in the titanium.

The rotation of the head of the femur in the acetabulum produces the hip's motion. In a prosthesis, this function is replicated by rotation of the →



A Co-Cr-Mo porous coated hip stem supports a Co-Cr-Mo femoral head, pivoting against a high-density polyethylene insert in a porous titanium-coated cup. Photo: iStock.

Photo: Symbios.

implant's head in the artificial bearing cup which is fixed in the acetabulum by means of the double coating technique or by screwing. Friction in this ball/cup joint must be as low as possible so that the patient's hip can recover its original range of motion. The prosthetic system also operates in a sea of body fluids, and must not corrode or interact with the body in harmful ways. The prosthesis materials and mechanical design must satisfy all these, sometimes conflicting, requirements.

The head of the femur, and the bearing cup, constitute the most complex part of the prosthesis. The successful operation of this pair of components determines the operation of the joint itself.

Biocompatibility and standardisation
Biomaterials (also called biocompatible materials) used for implant technologies (metals, ceramics and polymer) are subject to a strict standard in Europe. They are covered by directive 93/42/CEE, relating to non-living materials used in a medical device designed to interact with biological systems.

Recent improvements in machining and alloys have led to renewed interest in metal-metal bearings. The CoCrMo femoral head is housed in a CoCroMo bearing coated with porous titanium and hydroxyapatite, a pure bone crystal comparable to coral. Photo: Symbios.

The importance of reducing friction

There are four possible material combinations for the bearing cup and femoral head in hip prostheses (Table 1). Often the pair uses a metal head (Co-Cr28-Mo6 (ISO 5832-4) with 6% molybdenum or stainless steel) in contact with a polyethylene insert to minimise friction. The insert is housed in the metal bearing cup fixed in the acetabulum. To reduce polyethylene wear that may produce debris in the joint, thus influencing the durability of the implant (risk of loosening), ceramic (alumina) is sometimes used for the head instead of metal (alumina causes less erosion of the polyethylene than metal). This approach is not suitable for patients who engage in extreme sports like sky diving or mountain bike freeriding; the impacts related to these sports could overstress the more brittle ceramic head. The highly wear-resistant alumina is also difficult to machine, which raises the cost of the head. Nonetheless, ceramic-ceramic pairs (alumina head in a bearing cup equipped with an alumina insert) are finding wider acceptance for some applications.

Metal-to-metal combinations fell out of favour because of friction and wear problems, but they are now returning thanks to advances in the understanding of tribology (the study of friction and wear), improvements in machining precision, and more frequent use of high-carbon alloys (see below). A metal-to-metal combination using a cobalt-chromium-molybdenum (CoCrMo) alloy pair is particularly suitable for implanting large diameter femoral heads (40–56 mm) that help to avoid joint dislocation in highly active patients. Well suited to the static and dynamic balance of these patients, large diameter heads are also less affected by wear-related damage caused by debris around the femoral head.

CoCrMo: a winning combination

Each component of the prosthesis has unique requirements. The hip stem must be strong, not fail because of fatigue or overload, and not corrode; the femoral head must have ultra-low surface roughness and resist scratching and corrosion that can degrade joint performance. To meet these demands, high-performance biomedical materials are essential, as they offer the best possible compromise between strength, wear resistance and corrosion resistance.

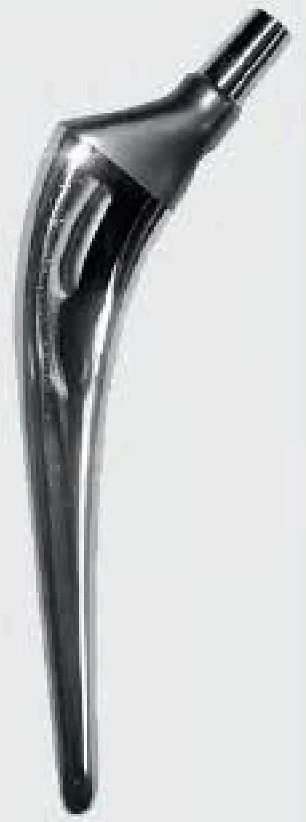
The high hardness of the cobalt-chromium-molybdenum alloy Co-Cr28-Mo6 makes it particularly suitable for the femoral head application. Molybdenum contributes strength and corrosion resistance to this alloy. The alloy has a very low coefficient of friction when paired with either a bearing cup of the same material (metal-to-metal) or one having a polyethylene insert (metal-polymer pair). →

Table 1. Hip protheses: joint cavity (acetabulum) / femoral head friction pairs

	Metal-polymer	Metal-metal	Ceramic-polymer	Ceramic-ceramic
Acetabulum (bearing cup)	PEHD Insert + titanium alloy bearing cup (Outside coating) porous titanium + hydroxyapatite)	CoCrMo alloy bearing cup (Outside coating) porous titanium + hydroxyapatite)	PEHD Insert + titanium alloy bearing cup (Outside coating) porous titanium + hydroxyapatite)	Alumina Insert + titanium alloy bearing cup (Outside coating) porous titanium + hydroxyapatite)
Femoral head	CrNi stainless steel Titanium alloy CoCrMo alloy	CoCrMo alloy	Alumina	Alumina

The alloy is generally delivered in bars 8–60 mm in diameter and either forged or machined on a digital lathe. The need for hard, wear-resistant surfaces dictates the choice of material. High-carbon (0.20–0.25% C) CoCrMo alloys are here preferred over low-carbon (0.05–0.08% C) variants.

Other alloys for cemented hip prostheses (femoral stems and bearing cups) may include austenitic stainless steels and titanium alloys (see box "Materials for differentiated uses").



Cemented femoral hip stem in stainless M30NW alloy with a 2–3% Mo content. Photo: Symbios.

Materials for differentiated uses

- Cobalt-chromium-molybdenum alloys are particularly interesting. In addition to their strength, toughness and resistance to wear, their elasticity is closer to that of bone than the elasticity of other alloys. CoCrMo alloy is mainly used for the femoral head and the bearing cup. It is also used sometimes for femoral stems.
- Cemented and screwed hip prostheses (femoral stems and bearing cups) generally use austenitic stainless steels for their corrosion resistance and strength. This can be M30NW (Cr21-Ni9-Mn4-Mo2.2-N0.4) or other grades: AISI 316L, ASTM F-55 or F-138 (Cr17–20%, Ni13–15%, Mo2–3%).
- Cementless hip prostheses (femoral stems and bearing cups), which simultaneously require strength and good adherence to bone, use titanium alloys (Ti6Al4V) coated with porous titanium and hydroxyapatite (HA).
- Ceramics (such as alumina (Al2O3) are used in hip prostheses for their low coefficient of friction as femoral heads and as inserts in the bearing cups.
- High-density polyethylene (HDPE) is used as an insert in the bearing cups of hip prostheses and as a tibial component (cushion) supporting the femoral implant in the knee.

The knee, a highly complex hinge

With many muscular points of attachment and a complex anatomy, the knee has stimulated many innovations in prosthesis design. The knee joint is much more delicate than the hip. It is composed of two separate joints: one between the femur and the tibia and the other between the femur and the patella, or kneecap. These joints are controlled by a complicated system of lateral and crossed ligaments that can apply considerable stress on the joint itself. To distribute these stresses evenly designers are creating prostheses that minimise friction while supporting significant mechanical loads (up to eight times the weight of the body when jumping, for example).

For Jean Plé, CEO of Symbios, a Swiss company specialising in hip and knee prostheses, the design and manufacturing of knee prostheses differs from hip prostheses because the geometry of the joint imposes more constraints: "The complex surface of the femoral component of the implant requires very costly and hard-to-perform machining. Hence, the solution of lost wax casting an alloy to give it its definitive form directly. The choice of CoCrMo, suitable for this technique, gives the implant the required mechanical qualities." The alloy offers the femoral component significant hardness and strength (it is more resistant to fatigue than titanium) and a low coefficient of friction. Pivoting on the base formed by the tibial component made of high-density polyethylene, it allows the repaired joint to recover all its rotation and extension capabilities.

The fact that wearers of prosthetic knees or hips now frequently practice sports proves that implant technology is truly robust. The materials used in implants provide the required mechanical, frictional and corrosion properties to allow implants to operate reliably for long times. Molybdenum, because of its beneficial effects on strength, fatigue resistance, hardness and corrosion resistance, plays an important role in this technology.

Photos: Symbios.