Implant materials for hip endoprostheses: old proofs and new trends

Abstract To judge the significance of a hip joint replacement, the clinical results over 10–20 years must be evaluated. Today, still over half of all hip endoprostheses involves cement fixation. The rest is un cemented, in direct contact with bone. Total hip prostheses with polyethylene cups are equipped either with cob-

Fixation principles for hip endoprostheses

The first usable hip prosthesis types from Moore, Thomp- son, McKee, Ring and Sivash in the 1950s were implanted and anchored directly in the bone without cement. Charn- ley’s cementation technique with self-hardening monomer and polymer methylmethacrylate provided immediate primary fixation for the cup and the stem and was the real breakthrough in hip endoprosthetics. Optimisation of the cementation technique by Ling [6], Weber [31] and Drae- nert [23] has resulted in the fixation of over half of all current hip endoprostheses using acrylate cement. Experience has shown that cement thicknesses of 3 mm on average (maximum 5 mm) are successful. Very thin cement layers tend to fracture early, and the resulting cement wear causes foreign-body granulomas, which leads to loosen- ing of the implant. Solid, perfectly anchored cement plugs, hardened according to specifications, exhibit good long-term stability.

In the 1970s and 1980s, many operators began to con- sider again cementless fixation for hip endoprostheses, because instances of unsatisfactory results were occasion- ally found where hip prostheses had not always been ce- mented optimally. The various hip prosthesis types used followed the following fixation principles:

- Macrostructures on cup and stem such as cup threads and holes, relief, recesses and steps on the stem; or crater-like, or special surfaces with beads or spongiosa-like structure
- Microstructures on cup and stem such as sintered-on metallic powder beads or titanium wires or coarse blast- ing of the metal surfaces
- Coatings on cup and stem using plasma spray methods to apply hydroxyapatite or pure titanium powder

Particularly successful are those cementless hip cups and stems which provide not only a very good primary fixa- tion by their press-fit design but also achieve secondary fixation and which are not only dependent upon the in- growth of osseous tissue into porous surface structures. If

Introduction

The clinical performance of various hip prosthesis types with revision rates under 20% and implantation times of up to 15 years provides valuable information about the direction in which design, fixation principles and material concepts should continue to be studied and optimised. This article deals especially with personal experience with various design concepts for the replacement of the hip joint [15, 37] using metallic materials, polymer synthetic materi- als, ceramic and coatings.
connective tissue is allowed to form at any time as a result of too much micromotion between the implant and the osseous bed, this will inevitably lead to loosening of the implant. There have been positive results with regards to bony ongrowth with surfaces which have been roughened by blasting or coating. Hydroxyapatite, as a substance similar to bone, has an additionally effect, but 10-year results are not yet available.

**Materials concepts for hip joint replacement**

**Hip ball head endoprostheses without cups**

In certain femoral neck fracture cases, a hip ball head endoprosthesis with a ball diameter as close as possible to that of the acetabulum is implanted. None of the polymer synthetic materials used to date (Plexiglas, polyethylene, polyacetal, polyester) has performed successfully clinically when articulating against bone/cartilage. In all cases, there was massive wear on the synthetic ball heads, with pronounced foreign-body reactions as a result [15].

On the other hand, good long-term performance has been obtained with ball heads made from the cobalt-chromium-molybdenum cast alloy Co-28Cr-6Mo (ISO 5832-4) and also the iron-chromium-nickel-molybdenum forging steel Fe-18Cr-14Ni-3Mo (ISO 5832-1) and aluminium oxide ceramic Al$_2$O$_3$ (ISO 6474). Metal ball heads can either be integral with the hip prosthesis stem or attached using a taper spigot. So-called duo-heads are mounted on small ball heads on the stem.

**Shell endoprostheses with cups**

The shell endoprostheses of the 1970s consisted of a cemented CoCrMo metal shell or an Al$_2$O$_3$ ceramic shell mounted on the spherically or cylindrically prepared femoral head and a cemented thin-walled polyethylene cup in the acetabulum.

The unsatisfactory long-term results are due on the one hand to the thin-walled, easily deformed polyethylene cups, and on the other to the biomechanically unsuitable load transfer conditions. The question is still open as to whether new materials concepts, such as the CoCrMoC metal/metal combination for cup and shell, and a cementless fixation for future shell endoprostheses will provide a solution.

**Low-friction head/cup combination with low wear**

The ball head of total hip endoprostheses must articulate in the artificial cup with minimum friction, so that as little force as possible is transferred to the prosthesis anchoring. During their functional life in the patient, both components should experience minimum change of shape due to creep and wear in order to avoid jamming of the ball head in the cup.

Ball heads made from polymer synthetic materials (polyethylene, polyacetal, polyester) have not performed well clinically in combination with CoCrMo metal cups. All ball heads of synthetic materials with convex articulating surfaces suffered massive wear, leading to foreign body reactions [40].

Likewise, cemented hip cups of polytetrafluoroethylene (Teflon), Teflon reinforced with microparticles (Fluorsint), and polyacetal combined with metal ball heads have not performed well clinically on account of high wear rates.

It was only with cups introduced by Charnley in 1963 using ultrahigh molecular polyethylene (ISO 5834-2) with a sufficient wall thickness of 6–8 mm combined with ball heads of FeCrNiMo forged steel (ISO 5832-1) that a satisfactory clinical result was achieved [1]. Yearly wear of the polyethylene cup of 0.1–0.3 mm and growing scratches on the soft steel ball head, which cause the wear to be increased still further, have to be reckoned with.

In the 1980s Charnley introduced the harder and more corrosion resistant iron-chromium-nickel-manganese-molybdenum-niobium-nitrogen forging steel Fe-20Cr-10Ni-4Mn-3Mo-Nb-N (ISO 5832-9) for the 22-mm ball head [27]. Long-term cup wear is expected to be lower, as the harder ball heads do not get scratched.

Metal ball heads in the titanium-aluminium-vanadium forging alloy Ti-6Al-4V (ISO 5832-3), used in the USA for many years, have not given good clinical performance combined with polyethylene cups. There were repeated occurrences of badly scratched titanium ball heads where 3-body wear occurred due to cement particles, with strong black discoloration of the surrounding tissue. Coating the titanium ball head with a 3–5 μm thin, titanium nitride layer with very high hardness makes the ball head surface extremely scratch resistant and thus solves the problem. Titanium nitride has been in clinical use since 1986 [26] for ball heads made from the titanium-aluminium-niobium forging alloy Ti-6Al-7Nb (SN 056 512 and ASTM F-1295, ISO 5832-11). Surface hardening of the polished titanium surface to a depth of only 0.1 μm using nitrogen ion implantation does not appear to be very promising, because the depth of the hardening should be at least 5 μm, better still 30 μm, as in the oxygen diffusion hardening process [26]. Such ODH-treated Ti-6Al-7Nb ball heads have been under clinical investigation since 1992.

Most metal ball heads (Figs. 1 and 2) implanted today are made from CoCrMo cast alloy (ISO 5832-4) or forging alloy (ASTM F-799). With these relatively hard and wear-resistant ball heads, a yearly polyethylene cup wear rate of 0.1–0.3 mm has to be reckoned with. To reduce polyethylene cup wear, it has been paired since 1975 with Al$_2$O$_3$ ceramic ball heads (ISO 6474) with very high hardness and good wettability with body fluid (Figs. 3 and 4). Clinical results showed that it is in fact possible to reduce the wear of the polyethylene cup to 0.05–0.15 mm per year [30, 42]. Even lower wear (0–6 μm per year) of cup and ball head can be achieved with the Al$_2$O$_3$ ceramic/ceramic combination of Boutin and Mittelmeier [11]. The ceramic cup must not, however, be implanted at