Alternative materials to improve total hip replacement tribology

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ABSTRACT An improvement in tribology of bearing surfaces is an effective means of increasing the longevity of total hip replacement (THR). Currently, 3 approaches are available to achieve this aim: first, use of highly cross-linked UHMWPE; second, aluminum oxide ceramic bearings, and third, metal-on-metal bearings.

Cross-linking reduces the wear resistance of UHMWPE markedly without impairment of other significant properties of the material. Simulator studies and some clinical long-term (10–22 years) follow-up surveys suggest an almost immeasurable wear of the highly cross-linked UHMWPE-based acetabular components during an expected clinical life span.

Bioinert alumina ceramic (aluminum oxide) was introduced 3 decades ago for THR-bearing surfaces to improve performance and longevity. Alumina ceramic is entirely biostable and bioinert and has good mechanical properties. For correctly positioned alumina-on-alumina bearings, the annual linear wear rate has been reported to be 3.9 μm. Alumina heads have been successfully used in combination with polyethylene sockets, but as regards wear, the best results have been obtained with alumina-on-alumina bearings. In ceramic THR bearings, precise manufacture and contact surface geometry, including optimal clearance, are most important. For the currently available products, the component fracture risk is almost nonexistent (less than 1 per 1000).

Metal-on-metal bearings were used in the early stage of THR surgery, although not all old designs were successful. More recent analyses of the early series have shown the advantages of metal-on-metal to be better and have led to a renaissance of this articulation. Initially, stainless steel was used because it was easy to manufacture and polish. Current metal-on-metal bearings are based on cobalt-chromium-molybdenum alloys with varying carbon contents. Such bearings are self-polishing. Linear wear rates remain at the level of a few μm a year.

An improvement in technology has increased the life span of the above three THR-bearing systems. Although the technical solutions differ considerably, they all seem to improve clearly the tribology and longevity of the THR. Each of these bearing concepts will probably permit the use of larger head sizes, to reduce the risk of impingement and luxations.

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For an artificial hip joint (THR), the best materials are selected as a compromise, bearing in mind tribological issues, corrosion environment and biocompatibility. Various components of the THR must be able to withstand and correctly transmit the fluctuating and cyclically-repeated forces caused by gravity and muscular action. Therefore, mechanical characteristics, such as strength, elasticity, toughness and ductility, are relevant factors. Low friction and low wear are desirable characteristics for the articulating surfaces of THR prostheses. In addition to different modes of wear, the implant materials also degrade in different ways in the very corrosive environment of the body fluids.

Table 1. Currently available UHMWPE acetabular liners having a high cross-link density are listed here

	Manufacturer	Radiation			Postirradiation thermal treatment	Sterilization method	Total radiation dose (kGy)
		temp. °C	dose (kGy)	type			
Longevity	Zimmer	~40	100	E-beam	Melted at 150 °C for 6 h.	Gas plasma	100
Durasul	Sulzer	~125	95		Melted at 150 °C for 2 h.	EtO	95
Marathon	Depuy/J&J	RT	50	Gamma	Melted at 155 °C for 24 h.	Gas plasma	50
XLPE	Smith & Nephew	RT	100		Melted at 150 °C (duration unknown)	EtO	100
Crossfire	Stryker/Osteonics/ Howmedica	RT	75		Annealed at 120 °C for a proprietary duration	Gamma (30 kGy) in nitrogen	105
Aeonian	Kyocera	RT	35		Annealed at 110 °C for 10 h.	Gamma (25–40 kGy) in nitrogen	60–75

Early experiences with Charnley teflon acetabular components showed, that not only low friction, but also low wear and good biocompatiblity of both solid and small particulate wear materials are essential to good clinical success and longevity of the THR. It also became evident that wear in synovial fluid or serum was much greater than in tests with water as the lubricant. Currently, the basic cemented traditional THR prostheses with small technical refinements, which have been developed over 3 or 4 decades, give, according to the Scandinavian hip registers, very good 10-year outcomes (better than 90%). However, aseptic loosening, caused to a great extent by adverse biological local reactions, induced by wear products from the articulating surfaces, remains a serious problem. Different types of technical improvements have been advocated recently to improve the THR bearings: 1) strongly cross-linked UHMWPE; 2) alumina-on-alumina and 3) metal-on-metal. These are different, but apparently successful ways of reducing wear and particulate debris that cause aseptic loosening. In the following, advocates of each of these concepts, who are actively involved in developmental research present their case.

Strongly cross-linked UHMWPE (Table 1)

The detrimental debris, which causes periprosthetic osteolysis and thus results in THR component loosening, is primarily generated by the adhesive/abrasive wear of ultra-high molecular weight polyethylene (UHMWPE) acetabular components. Cross-linking has been reported in both in vivo (Oonishi 1995, Grobbelaar et al. 1999, Wroblewski et al. 1999) and in vitro (McKellop et al. 1999, Muratoglu et al. 1999, 2001a, 2001b) studies to improve markedly the wear-resistance of UHMWPE. Crosslinking can be achieved by generating free radicals along the backbone of the long chains that make up the polyethylene molecules. The free radicals generated in adjacent chains combine with each other, forming carbon-carbon covalent bonds, which are the so-called cross-links. The free radicals can be generated and cross-linking can be achieved by exposing the polymer to ionizing radiation or by using peroxide or silane chemistries. Several studies have shown the value of an increase in cross-link density on the in vitro and in vivo performance of polyethylene acetabular components. The methods included cross-linking polyethylene with high dose (1000 kGy or 100 Mrad) gamma radiation in air (Oonishi 1995), gamma radiation (100 kGy) in the presence of acetylene (Grobbelaar et al. 1999), and silane chemistry (Wroblewski et al. 1999).

Long-term retrospective radiographic studies in patients carried out by three groups of investigators all showed markedly improved wear-resistance in vivo in acetabular components made of these strongly cross-linked polyethylenes (Oonishi 1995, Grobbelaar et al. 1999, Wroblewski et al. 1999). Oonishi's report showed a decrease in the average rate of femoral head penetration (0.072–0.076 mm/year) for the 1000 kGy-irradiated UHMWPE, as compared to the control UHMWPE (0.098–0.25 mm/year) that had been gamma-sterilized in air. Grobbelaar et al. (1999) reported two clinical follow-up series with acetabular components that were gamma radiation (10kGy) cross-linked in the presence of acetylene gas. The first was a 14–22-year follow-up (average 15.5 years) of 64 hips of which 56 had no measurable wear and a total of 1–4 mm linear penetration in the remaining 8 cases. The average calculated wear rate of this entire series was 0.011 mm/year. The second series was a mean 16 (13–22)-year follow-up of 39 hips with no measurable wear in 30 cases and a total of 0.7–1.5 mm linear penetration in the remaining 9 hips. Of the 103 hips in these two series at an average of 16 years, 84% showed no measurable wear. Wroblewski et al. (1999) reported the wear of the silane cross-linked polyethylene at a mean clinical follow-up of 10 years in a group of 14 hips. After an initial "bedding-in" penetration of 0.2–0.4 mm/year, presumably representing creep, the subsequent average penetration rate decreased by an order of magnitude to 0.02 mm/year, presumably representing true wear. The conclusion to be drawn from these studies, including 145 cases followed 10–22 years in vivo, is that cross-linking very effectively increases the wear resistance of UHMWPE in vivo regardless of the cross-linking method used. The aforementioned highly cross-linked polyethylenes were not commercially available and were manufactured by the respective group of investigators themselves.

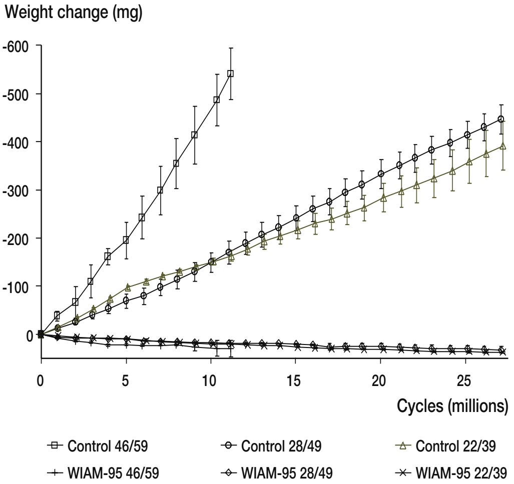

Figure 1. The average change in weight of a type of strongly cross-linked UHMWPE (warm, irradiated with adiabatic heating and subsequent melting–WIAM-95/Durasul TM) and conventional acetabular liners as a function of simulated gait cycles on a hip simulator are shown here. The inner and outer diameters of the liner/shell combinations are marked in the legend—i.e., WIAM-95 46/59 refers to a liner made of WIAM-95 cross-linked UHMWPE with an inner diameter of 46 millimeters and shell outer diameter of 59 millimeters. The thicknesses of the liners used in the hip simulator testing were 3 mm in all of the WIAM-95 liners, which represents an extreme worst-case scenario, except for the liners tested against 22 millimeters head size with a thickness of 5 mm (Muratoglu et al. 2001a).

The contemporary approaches to cross-linking differ in some ways from these historical examples. Today, radiation chemistry is the preferred method of crosslinking and neither peroxide nor silane chemistry is used. In addition, postirradiation thermal treatment steps are employed to reduce the concentration of residual free radicals and improve the long-term oxidative stability. There are several commercially available contemporary approaches for improving the wear and oxidation resistance of polyethylene by radiation chemistry for applications in total hip arthroplasty.

Postirradiation thermal annealing is used after the exposure of UHMWPE to ionizing radiation, such as gamma or e-beam. Radiation generates free radicals, most of which recombine with each other to form crosslinks. However, some free radicals remain trapped in the crystalline regions and initiate the cascade of events that cause oxidation and subsequent embrittlement of polyethylene. Although this oxidation does not increase the wear rate, its poor desisgn has, in some cases, lead to mechanical failure of the liner. Considering the potentially adverse effects of oxidation, and the advantages of the increasing crosslink density on wear resistance, it is advisable to reduce the concentration of the residual free radicals after irradiation (McKellop et al. 1999, Muratoglu et al. 1999, 2001a, b). Since these radicals are present in crystalline domains, the most effective method of eliminating them is to melt polyethylene after irradiation. Melting eliminates the crystalline domains and liberates the trapped radicals, allowing rapid recombination, and consequently elimination of residual free radicals.

Extensive data are available from hip simulator studies showing the improvement in the wear resistance of contemporary cross-linked polyethylenes (McKellop et al. 1999, Muratoglu et al. 1999, 2001a, b). A typical example of electron-beam crosslinking has been reported by Muratoglu et al. (2001). Figure 1 compares the wear behavior of this electron-beam crosslinked UHMWPE and conventional UHMWPE as a function of simulated gait cycles and femoral head sizes. In this study, the conventional UHMWPE acetabular liners lost weight steadily because of adhesive/abrasive wear, the rate of which increased with femoral head size. In contrast, the electron-beam crosslinked UHMWPE liners showed no detectable change in weight. With electron-beam cross-linking, this marked increase in wear resistance was very independent of femoral head sizes, from 22 mm to 46 mm in diameter.

Clinical follow-up studies are currently in progress to assess radiographically the in vivo wear behavior of the contemporary markedly cross-linked UHMWPEs at several clinical centers around the world. Most of these radiographic studies started in 1999 and early results are now available. Only after 5 years of in vivo service does it seem likely that the radiographic data will show the difference in wear rates due to creep in clinical use between the contemporary markedly cross-linked and conventional UHMWPE acetabular liners. Up till now, early clinical experience with the closely cross-linked UHMWPE components has had no adverse effects on liner performance, and there have been no reports of an early increase in wear or failure. A recent study of a group of closely cross-linked acetabular components retrieved at revision surgery indicated a marked reduction in loss of material from the articular surfaces up to 18 months in vivo (Muratoglu et al. 2002).

The principal implication of this increase in resistance of these components is the potentially large reduction in periprosthetic lysis rate in vivo. Moreover, the low wear also permits the use of femoral heads of larger diameter, which means a greater range of motion, enhanced activities of daily living, a greater intrinsic stability of the implant, a reduced incidence of subluxation, a reduced incidence of dislocation, and less frequent impingement of the femoral neck on the polyethylene. Furthermore, the greater range of motion available offsets the inherent errors in acetabular placement thus providing an increased margin of safety (Jaramaz et al. 1999).

Alumina-on-alumina bearings

An aluminum oxide ceramic head coupled with an acetabular component inlay of the same material has proved to be reliable in clinical use (Mittelmeier and Heisel 1992). In combination with modular socket and stem THRs, these hard-on-hard bearings are, according to clinical data, a very appropriate choice, especially for young and active patients (Sedel et al. 1994). Studies by Böhler et al. (1994, 2000) confirm the results of several others, indicating very low linear wear rates and low concentrations of wear particles in periprosthetic tissues. Tribological and histological studies of retrieval specimens have confirmed the superiority of aluminum oxide ceramics in terms of wear resistance, bioinertness and reduction in local cellular response to wear particles, as compared to other bearing couples (Walter 1992, Böhler et al. 2000, Mochida et al. 2001). There are 4 main reasons for using aluminum oxide ceramic THR bearings: 1) wear resistance; 2) good clinical biocompatibility; 3) possibility of using aluminum oxide bearings in combination with various THR designs and 4) good clinical results in follow-up studies.

Böhler et al. (2000) have found that the wear properties, including lubrication, friction and wear in alumina-on-alumina bearings are excellent. The wear rate of well-positioned and well-designed aluminum oxide THR bearings was 3.9 μm/year. Wear rates above 6.5 μm/year were found only in cases with neck or rim impingement, poor design or manufacture of the wear couples, and/or malalignment (Walter 1992).

Mochida et al. (2001) reported their findings in 12 retrieved THRs with alumina-on-alumina bearing couples. The revisions were done because of loosening of one or both components and included 4 implants of old design and 2 retrievals from a patient who died of myeloma (both THRs in the latter patient were stable and showedsevere neck-rim impingement and excessive wear) (Table 2). Mochida et al. also measured the sphericity deviations by the least square circle method (LSC method; ISO 6318) and calculated the annual wear rates of both the ball head and socket of the insert. The mean calculated wear rates were 24.3 μm (ball heads 14.7 μm and sockets/inlays 9.6 μm); and 46.7 μm (24.3 μm for heads/22.4 μm for sockets) in the 2 cases with stem and socket loosening; in a case revised for infections, 14.6 μm (10.1 μm/4.5 μm); in the 5 cases revised for socket loosening

Table 2. Wear data of 12 explanted cementless modular THRs with alumina-on-alumina bearings. 8 cp-Ti modular sockets had inserts with BIOLOX alumina standards and were combined with Ti-alloy stems. 4 monobloc alumina sockets with alumina standards, according to ISO 6474, were combined with Co-alloy stems

Case	Alumina quality	Diameter of head	Time in vivo (months)	Inclination of sockets	Indication for revision	Sphericity deviations in μm/year	
						Ball head	Socket
1	Biolox	32	29	46	socket loosening	1.9	2.6
2	Biolox	32	33	46	socket and stem loosening	7.6	17.9
3	Biolox	28	60	38	socket loosening	31.8	3.9
4	Biolox	32	36	36	socket loosening	1.1	n.m.
5	Biolox	28	83	41	socket loosening (died)	0.49	0.35
6	Biolox	28	7	24	impingement (died)	15.3	2.1
7	Biolox	28	12	26	Impingement	43	10.4
8	Biolox	28	32	40	infection	3.2	12.4
9	ISO 6474	32	136	56	socket and stem loosening	40.9	27
10	ISO 6475	32	156	44	stem loosening	1.7	0.9
11	ISO 6476	32	135	45	stem loosening	n.m.	16.5
12	ISO 6477	32	237	56	socket loosening	15.3	11.2

and 10.4 μm (1.7 μm/8.7 μm); in the 2 cases with loosening of the stem.

Periprosthetic tissues of 9 reoperated alumina-on-alumina THRs with monolitic sockets implanted between 1976 and 1979, and of 11 reoperated THRs with modular prostheses from the period beginning 1990 were analyzed as regards the sizes of the alumina wear particles, generated according to a standardized research protocol (Bauer 1996). Their sizes were measured by SEM and EDXA techniques. Single alumina particles and conglomerates ranged from 0.13 to 78.4 μm (average 0.39 μm, SD 0.12 μm) on the 0.1 μm pore carbon filter. Thus, wear measurements of failed alumina bearings showed that the particle sizes remain, on average, in the range where the local cellular irritation is known to be very limited.

Alumina ceramic bearings are biocompatible in bulk and small particulate form. Sintered surgical grade alumina does not release soluble compounds because it is chemically inert in its most oxidated form. The above-described wear particles, which can be found in the periprosthetic tissues shortly after implantation, are not soluble and are phagocytosed by macrophages more easily than other THR material wear products. The chemotactic response of macrophages, loaded with alumina particles, were found to be benign: the release of TNF-alpha and PGE_2 was significantly lower than the reaction caused by high-density polyethylene particles (Sedel et al. 1992).

Immunohistochemical stainings (Table 3) were done to help determine the origin of the resident periprosthetic cells irritated by the particles, as compared to reactions caused by other THR materials (Willert et al. 2000, Böhler et al. 2002). While all THR material wear particles caused a macrophage response, cases with alumina ceramic bearings showed no accompanying lymphoid cell response, which means that alumina does not cause any local or systemic allergic reaction, unlike other bearing materials (Brodner et al. 1997). No metabolic disturbances or systemic reactions are known to occur with alumina.

Alumina-based bearings can be used in combination with various THR designs and systems. In early years, so-called monobloc conically-threaded or spherical press-fit cups made of alumina ceramic were used with varying success. Although several authors reported acceptable mid- and long-term results (Nizard et al. 1992, Sedel et al. 1994), these earlier designs had problems due to the differences between elasticity modules of bone and implant. Some of these implants were uncemented. This did not allow sufficient osseous fixation. The numerical difference in elasticity is, in fact, more than one hundredfold. This nonisoelasticity of the monobloc

Table 3. Data on immunohistochemical staining of histological specimens. Amount of lymphoid cells (T- and B-cells) and of activated macrophages in periprosthetic tissues

Immunohistochemical staining (label)	Alumina ceramic bearings [a]	Metal-on-metal bearings [b]	Polyethylene inserts/ alumina ceramic head bearings[a]
T-cells (CD 3)	0 to 1+	always	1+
B-cells (CD 20)	0	always	0
Activated macrophages (CD 68)	0 to 1+	0–1+	1+ to 2+

[a] Mochida et al., Clin Orthop 2001; 389: 113-25
[b] Willert et al., Osteologie 2000; 9; 2-16

alumina designs is, in our view, one of the reasons which led to poor long-term fixation.

Nowadays, these historical alumina THR prostheses have been replaced by modular systems in which a taper fixation between ball heads/stems and sockets/inserts secure both components. As regards the taper fixations of both inlay and ball head, European standards are implemented in most available THR systems. For this reason, one can combine the excellent tribological properties of alumina ceramic bearings with several successful THR systems and designs.

Recently, the alumina-on-alumina-based THRs have become very popular. However, many surgeons are concerned about the brittleness of the alumina ceramic, which may entail a risk of component fractures. THR register surveys—e.g., in Finland—indicate that, with the current alumina-on-alumina bearings, the risk of component fracture can be ignored. The widespread introduction of standardized cones on modular implants has made it very easy to combine full alumina components with various THR designs, even in revision cases where only part of the components are replaced. However, the taper design must be fully compatible.

For more than 27 years, components made of aluminum oxide ceramic have been used in clinical practice. During the developmental phases, poor results led to changes in designs of improperly-manufactured prostheses, and retrieval analyses have given knowledge about the correct use of alumina ceramic bearing components in combination with modular, nonceramic components (Sedel 2000). From tribological analyses of retrieved alumina ceramic bearings, we learned that the lowest sphericity deviations are to be expected in socket components implanted at an inclination between 35 and 45 degrees. Less inclination impairs the patient's ability to flex the hip joint, and an inclination exceeding 45 degrees entails a risk of edge loading, impingement and chipping off at the rim of the ceramic liner.

Metal-on-metal bearings

1st generation metal-on-metal. All metal bearings were used in the early phase of development of the modern THR. Such bearings were initially better than metal-on-composite ones. Probably, the first true metal-on-metal THR was the prototype developed by Philip Wiles in 1938 (Wiles 1957). These were unsuccessful because of the low quality of stainless steel used for the prosthesis, poor manufacture and lack of adequate fixation. In the early 1950s, McKee (1951) did a small series of THRs using an all-metal artificial joint made of stainless steel which were uncemented and found that they could not be integrated by bone. The introduction of methylmethacrylate bone cement improved the quality of such THRs substantially. Later in the 1960s and early 1970s, the metal-on-metal design by McKee and Farrar became popular and successfully competed with the Charnley type metal-on-polyethylene designs. These prostheses were made of CoCrMo alloy and had head diameters of 32–42 mm. The early versions of these prostheses had a poor fit between the head and socket, while the quality clearly improved with time. Objections to the all-metal bearings particularly concerned friction, lubrication and wear (Willert et al. 1996). The marked amount of friction measured in the early McKee-Farrar prostheses was thought to cause forces/torque higher than the bone-cement interface could withstand. Recent tribological work with simulators has confirmed that the wear was very low and loosenings were more probably caused by mechanical forces than biological wear-induced failures. The bearing qualities and tribological properties of the later McKee prostheses were, in fact, very good. Retrospective studies have shown that hardly any wear occurred so long as the bearing components were properly matched by 0.15–0.20 μm clearance to allow a lubricating fluid interface. The 1st generation of metal-on-metal prostheses were gradually abandoned in the 1970s because the overall results achieved by the Charnley type low-friction arthroplasties appeared to be better.

2nd generation metal-on-metal. Weber of Switzerland was one of the first to realize that in fact the low wear rates of metal-on-metal THRs could be related to a reduction in loosening (Weber et al. 1989). His observations indicated that technically well-implanted 1st generation metal-on-metal prostheses usually gave very good clinical and radiological results. With the slogan "back to the future", Weber together with his industrial partner initiated the development of 2nd generation metal-on-metal THR prostheses. The main aims were the following: 1) to create an optimal clearance between a 28 mm head and liner; 2) to optimize the roughness of the CoCrMo alloy by using a wrought rather than cast manufacturing method; 3) develop tribologically optimal head roundness and sphericity of the liner; and 4) to obtain the best quality control. The resulting Metasul metal-on-metal THR prosthesis was introduced for clinical use in 1988. Clinical and tribological testing led to approval of this design by the French Ministry of Health in 1998, and by the FDA in 1999. Currently, more than 150,000 Metasul THRs have been implanted throughout the world. Most of the main implant producers have a metal-on-metal THR system available. The designs include cemented and uncemented versions. The metal socket liner is usually polyethylene-backed in order to reduce the difference between the elasticity of metal and bone. The damping effect of polyethylene may be a reason for thegood results of more recent metal-on-metal bearings. Because 28 mm heads are popular, the risk of impingement exists with all hard-on-hard bearings if the positioning of the implant components is less than perfect. The 3rd generation metal-on-metal prostheses will probably have heads of larger size, which is possible because of low friction and low wear with metal-on-metal bearings (Sieber et al. 1999).

The wear of the Metasul metal-on-metal prostheses has been studied in retrieved prostheses and using simulator tests. During the first year after implantation, there is an initial run-in phase which is followed by a steady-wear phase. The linear run-in phase wear rate is 20–25 μm/year, which corresponds to a volumetric wear rate of about 2 mm^3/year. During the steady-wear phase after the first year of use, the linear wear continues to be 5 μm/year for several years, which corresponds to a volumetric wear rate of 0.2 mm^3/year. Such wear rates are similar to those of exact masurements of retrieved alumina-on-alumina THRs. Indeed, the wear of these metal alloy's dispersed carbide ceramic particles resembles that of ceramic-ceramic pairs. The current CoCrMo-based metal-on-metal bearings are to a certain extent self-polishing and very strong. Some studies suggest periprosthetic lysis occurs less with metal-on-metal THRs than with metal or alumina and conventional polyethylene (Doorn et al. 1996).

The metallic wear particles are smaller than 100 nanometers. As such, they are too small to affect the resident macrophages (Willert et al. 1996, Green et al. 1998). Since the wear properties are good, the total mass of the generated particles remains low.

In patients with metal-on-metal THRs, the Co and Cr concentrations in blood serum and urine are high (Brodner et al. 1997). They seem to fall after the initial 1-year run-in phase. It has been thought that one should not have a metal-on-metal THR in patients with chronic renal failure. Visuri and Koskenvuo (1991) showed that over a period of 15 years there was no increase in the risk of cancer in patients with McKee-Farrar type CoCrMo metal-on-metal THRs. Hypersensitivity to the metals is possible, but there are hardlyany data concerning its clinical relevance (Willert et al. 2000) and no proof that the release of metal is teratogenic. Critical surgeons suggest that metal-on-metal prostheses should not be inserted in fertile women yet.

Extensive clinical experience has accumulated about current and older metal-on-metal designs. Such bearings are tough, nearly unbreakable and generate very little wear debris over a long period. Experimental studies of diamond coating of the metallic surfaces may improve the wear properties of the metal-on-metal bearings (Santavirta et al. 1999).

Comments

It has become evident that better tribological properties of THR bearings are essential for the longevity of the artificial joint. Correct counterface, material combinations, surface finish, and tolerances of contact surfaces are important aspects of minimizing friction, wear and corrosion. Simulator testing and THR registers have become useful for evaluation of THR designs and materials. Metal-on-metal and alumina-on-alumina-based prostheses are classic designs which have solved the basic tribological problems. In addition, the strongly cross-linked polyethylenes have shown excellent wear properties both in vitro and in vivo with 10–22 years o follow-up. Metallic bearings are tough and do not fracture. Alumina is very inert and prsent designs entail no risk of component fracture. The advantages of polyethylene bearings are better shock absorption and a slight impingement is not necessarily very serious.

A vital point is that major improvements in manufacturing have occurred during the last few decades—e.g., wrought and powder-processed metal alloys have replaced conventionally cast alloys. Powder synthesis and better processing have significantly reduced the flaws and serious earlier failures of ceramics. Current data have shown that each of the bearing concepts discussed here (strongly cross-linked polyethylene paired with a hard head, alumina-on-alumina or metal-on-metal) seems to improve definitely the tribology and longevity of the THR. As experience from larger well-planned clinical studies accumulates, it will become clear whether the improvement tribological properties of the implants really prolongs their clinical longevity. Small differences in the longevity and clinical outcomes of the various systems can be studied by using the major national THR registers and well-planned large clinical outcome studies during the years to come.

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