MENTORS IN ORTHOPEDICS

DIFFERENT BEARING OPTIONS IN THA – WHAT HIP SURGEONS SHOULD CONSIDER

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SUMMARY

Background: Total hip arthroplasty (THA) demonstrates high long-term survivorship, yet aseptic loosening remains a primary cause of late revision. This failure is frequently driven by polyethylene wear debris and subsequent macrophage-mediated osteolysis. While various bearing surfaces have been developed to mitigate these complications, clinical selection remains complex due to the distinct mechanical and biological profiles of each material combination.

Objective: This review evaluates current bearing surface options in THA, analyzing the clinical performance, advantages, and complications associated with polyethylene, ceramic, and metal articulations.

Key Points: Highly cross-linked polyethylene (XLPE) significantly reduces linear penetration compared to conventional ultra-high molecular weight polyethylene, with antioxidant-doped variants further resisting in vivo oxidation. Ceramic-on-ceramic (CoC) bearings provide optimal wear resistance and biocompatibility, though they are associated with risks of component fracture and audible squeaking. The adoption of larger femoral head diameters (>32 mm) has improved joint stability without compromising the wear rates of XLPE or ceramic liners. Conversely, metal-on-metal bearings have been largely discontinued due to adverse reactions to metal debris. Recent evidence suggests that ceramic femoral heads may reduce the incidence of trunnionosis at the modular head-neck junction compared to metallic alternatives. Registry data indicate a global trend toward increased utilization of XLPE and ceramic components.

Conclusion: Optimal bearing selection requires balancing wear resistance against mechanical stability. CoC is recommended for young, high-demand patients, while XLPE provides a reliable, versatile option for older populations. Ultimately, precise surgical positioning and component handling are as critical to long-term prosthesis survival as the material properties of the bearing surface.

KEYWORDS

Arthroplasty, Replacement, Hip; Hip Prosthesis; Polyethylenes; Ceramics; Prosthesis Failure

INTRODUCTION

Total hip arthroplasty (THA) is widely considered to be one of the most successful surgical procedures in orthopedics. It is associated with high satisfaction rates and significant improvement in quality of life following surgery [1,2]. According to recently published data from the British National Joint Registry, the cumulative survival of THA at 13 years is 93.2%, with 80% of implants surviving up to 20 years [3]. However, according to the Australian National Joint Replacement Registry, failures are still recorded, and causes of revision of THA are, in order of frequency [4], loosening, fracture, dislocation, infection and osteolysis at more than 10 years of follow-up. Regarding aseptic loosening, osteolysis and material wear are the most common causes of revision for failures occurring at more than one year after the index procedure [5,6].

Several combinations of liners and heads are available, each one having advantages and disadvantages. Wear and osteolysis represent a concern for conventional PE bearings (with metal or ceramics heads). Particulate debris and resulting biologic response play a key role in osteolysis and loosening. PE particulate debris activate macrophages that release an array of cytokines and pro-inflammatory mediators in the joint fluid resulting in the recruitment, multiplication, differentiation, and maturation of osteoclast precursors with subsequent bone resorption [7]. On the other hand, despite ceramic debris are not entirely inert and might induce inflammatory response and fibrotic tissue changes [8], they are several thousand time less as compared with PE articulation, leading to less response [9]. For this reason, the main warnings related to ceramic-on-ceramic (CoC) bearings are the risk of breakage and noise following arthroplasty. Adverse Reaction to Metal Debris (ARMDs), including metallosis, pseudotumors and Aseptic Lymphocyte-dominated Vasculitis-Associated Lesions (ALVAL), represented the main worries for metal-on-metal bearings and are mainly mediated by immunologic response. Furthermore, the same reactions may be found in patients undergoing THA using metal head and developing trunnionosis at the head-neck taper junction.

There is limited evidence regarding comparative effectiveness of various bearings. A meta-analysis comparing RCTs with a minimum of 2 years of follow up in patients younger than 65 years found similar short- to mid-term survivorship among CoC, ceramic-on-crosslinked polyethylene (CoXLPE) and metal-on-crosslinked polyethylene (MoXLPE) [10]. Globally, there has been an increased use of ceramic heads in the last years, but metal-on-polyethylene (MoP) is still widely used [11]. However, diversity still exists with regard to the use of the bearing options on an international scale, and in Europe clear differences appear, such as the wide use on MoP in Northern Europe in contrast to Germany, where ceramic-on-polyethylene (CoP) is the most frequently used coupling. The purpose of this article is to provide an overview of the available bearing option in THA, discussing advantages and drawbacks (Fig. 1) [12].

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Table 1. Main disadvantages for each bearing surface

Couplings	Main disadvantage
Metal-on-polyethelene	Wear and osteolysis
Ceramic-on-polyethelene	Wear and osteolysis
Metal-on-XLPE	Decreased mechanical properties
Ceramic-on-XLPE	Decreased mechanical properties
Ceramic-on-ceramic	Breakage and squeaking
Metal-on-metal	ARMD (ALVAL, high ion levels, osteolysis, pseudotumours)

Notes: XLPE, highly cross-linked polyethylene; ARMD, adverse reaction to metal debris; ALVAL, aseptic lymphocyte-dominant, vasculitis-associated lesion

Figure 1: Disadvantages of bearing surface.

CONVENTIONAL AND CROSS-LINKED POLYETHYLENE

Since 1962, when Sir John Charnley introduced the low-friction arthroplasty, different types of modifications of polyethylene (PE) have been undertaken. Originally, Ultra-High Molecular Weight PE (UHMWPE) replaced the high molecular weight (HMWPE), increasing its wear resistance. To further improve the clinical performance of UHMWPE, further enhancements were obtained including carbon-reinforced, highly crystalline, acetylene cross-linked, and high cross-linked polyethylene (XLPE). The latter is currently the most frequently used [10]. In a review from 2011, Kurz et al [13] found a consistent reduction of linear penetration with use of XLPE and reduced pooled odds ratio of 0.13 (95% CI 0.06 to 0.27) when compared with the earlier standard UHMWPE. Johansson et al [14] specifically studied cemented and cementless cups of the same design, but with use of either conventional or XLPE reported in the Nordic Arthroplasty Register Association (NARA) database. Femoral head sizes of 28 and 32 mm and both metallic and ceramic bearings were included. Four cup designs were available for this type of analysis, three cemented and one uncemented. Increased revision rate due to aseptic loosening was observed for two of the designs with use of conventional polyethylene and one of them also showed increased risk of revision due to any reason after a follow-up of eight to 10 years.

Cross-linking process and sterilization can produce free radicals, which cause surface oxidation leading to a decrease of mechanical properties of PE. This has also been showed in vivo by Engh et al. in a ten-year follow-up study [15] in which PE liners sterilized by oxygen-free gamma irradiation showed less head penetration and less osteolysis when compared with both gas plasma and gamma irradiation in air. For this reason, sterilization in inert environment is favorite. With use of radiostereometric analysis (RSA) Digas et al.[16] observed an average mean wear rate of less than 0.1 mm per year for conventional polyethylene cups or liners sterilized with gamma irradiation. Cups and liners sterilized with ethylene dioxide showed more than 50–100% higher wear rate than the gamma-sterilized implants studied. In a previous study Nivbrant et al.[17] had shown that use of alumina ceramic heads could reduce the annual wear rate of gamma- irradiated cups down to around 0.04 to 0.05 mm, but similar wear rates have also been found with use of metallic heads articulating against low-dose gamma-irradiated polyethylene. Post-irradiation thermal processes (annealing and remelting) have been introduced to reduce freeradical derived from cross-linking. Recently, XLPE liners with the addition of antioxidants such as Vitamin E have been introduced into the market with the aim of reducing the oxidation in vivo. The Vitamin E can be mixed in PE powder or added through diffusion after machining. The rationale for Vitamin E addition is to act as an antioxidant reacting with the free radicals that remain instead of oxygen [18]. There was found no evidence for difference in revision rates nor linear and volumetric wear between MoP and CoP bearings in the randomised controlled trials currently available[19]. No long term RCTs have compared Met-XLPE vs Cer-XLPE [10] so far.

CERAMIC-ON-CERAMIC (COC)

Almost 50 years ago, alumina ceramic was introduced in total hip replacements by Boutin [20]. Ceramic bearing surfaces have been developed as an alternative to metal-on-polyethylene bearings in total hip arthroplasty (THA) in an attempt to reduce wear and improve implant longevity [21].

In more detail, the first ceramic acetabular components were introduced in the 1970s by Pierre Boutin in France as cemented liners and in 1974 by Heinz Mittelmeier in Germany as cementless threaded liners and skirted heads. This generation of ceramics had a high rate of aseptic loosening and failure due to the poor fixation of both cemented and cementless implants, inadequate designs such as the bulky skirted heads and the strength problems due to the grain size of the first generation of alumina. Nowadays, the most commonly used ceramic is the alumina matrix composite (AMC) (Biolox Delta; CeramTech AG, Plochingen, Germany). There are some studies showing the excellent results for cermic on ceramic (CoC) bearings. Solarino et al.[22] in their clinical experience had 68 arthroplasties and no wear of the ceramic at an average follow-up period of 13 years, confirming the findings of previous clinical studies [23,24]. The main problems of CoC are: brittleness (fractures of femoral head) and the squeaking (high pitched, audible sound that occurs during movement of the joint). However, enhancements in ceramics over time have reduced these issues. The features of the first three generations of ceramic are shown in the (Fig.2) [25].

Properties of ceramics	Alumina ceramic ISO 6474	First and second generation alumina	Third generation alumina
4-point bending strength (MPa)	400	500	580
Average grain size (µm)	About 4.5	<3.2	<1.8
Density (g/cm3)	3.94	3.96	3.98
Hotisostaticpressing	No	Yes	Yes

Ball head	Cup/liner	Wear rate
Third-generationceramic	UHMWP	0.11 mm/year
Second-generationmetal	UHMWP	0.085 mm/year
Second-generationmetal	Metal	0.0063 mm/year
Third-generationceramic	Ceramic	0.004 mm/year

Figure 2: Properties of ceramics

The AMC bearing has a smaller grain size (less than 0.8mm) compared with the grain size of third-generation alumina (1–5 mm). (Fig.3)

Parameter	Thirdgeneration(Biolox Forte)	Aluminamatrixcomposite (Biolox Delta)
Al_2O_3(V/v)	>99.8	About 81.6
ZrO_2(v/v)	No data	About 17
Other oxides (v/v)	Rest	About 1.4
Density (g/cm3)	3.98	4.37
4-pointbendingstrength (MPa)	580	1384
Fracturetoughness(MPa m1/2)	3.2	6.5
Grain size (µm)	3	0.6
Wearvolume($mm^3/10^6$ cycles)	1.84	0.16

Figure 3: Features Biolox Forte vs Biolox Delta.

The prevalence of squeaking was reported to be around 0.5% by Walter et al. [27] but 10.6% by Cogan et al. [28]. Another study showed that the prevalence could reach up to 24.6%. [29] meaning that this is an issue related to the whole system which includes cup and stem design and thickness, not just ceramics. Furhtermore, younger age, obesity, higher activity level may facilitate this problem. Such variation could be ascribed not only to the difference in sample sizes among the studies but also to inevitable subjective bias due to a lack of unified scales for noise assessment. Implant position and orientation can play a key role in causing hip squeaking. Walter et al.[30] proved that high or low anteversion and inclination of the acetabular component were associated with squeaking. In patients without squeaking, 94% of the implants had 25° ± 10° anteversion and 45° ± 10° inclination while only 35% of squeaking hips were within this range. Factors involved in the squeaking may be edge loading, micro-separation, edge impingement, third bodies and linear fracture. More precisely, under certain circumstances, the contact point between the femoral head and the liner would move over the hard edge, leading to an increase in stress (referred to as edge loading), hence causing stripe wear. Impingement between the femoral neck and acetabular cup could presumably be caused by malposition, or that improper design of the implants could produce third bodies [31,32]. Metal debris from impingement could fall inside the bearing surface and disrupt the lubrication film, which would bring about an increased wear rate of the ceramic surfaces, thus producing ceramic debris. Third bodies composed of both metal and ceramic debris further facilitate abrasion of the joint bearing surfaces. (Fig.4) [33]

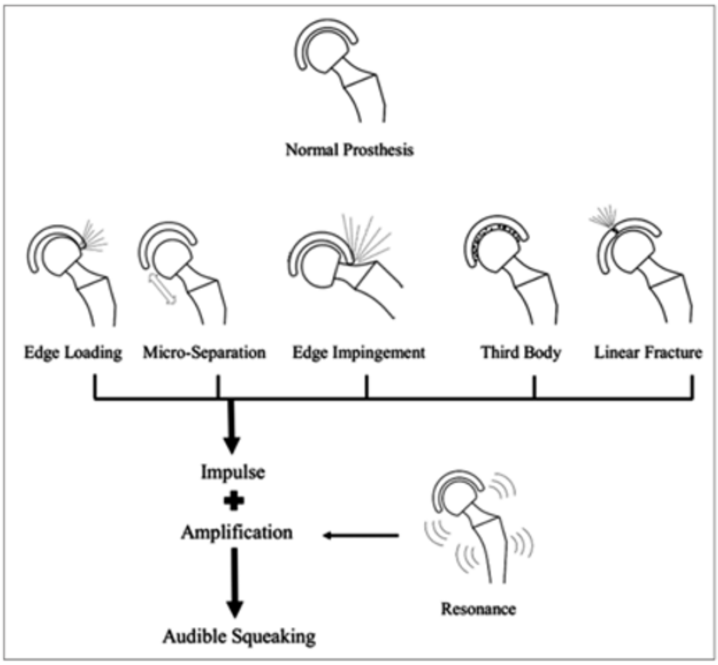

Figure 4: Proposed mechanisms of squeaking in CoC THA.

HEAD SIZE AND LINER THICKNESS

Both CoC and CoXLPE functioned well, with no osteolysis at mean of 17.1 year follow-up [34]. The improved wear resistance made the use of larger heads possible (32 mm and 36 mm depending on the cup size) improving joint stability. Larger diameter heads are associated with increased wear and revision rate for osteolysis when coupled with standard PE [35]. Interestingly, no increase in XLPE wear rates with the use of larger diameter heads (> 32 mm) were reported in some studies [36]. Moreover, good results with XLPE at a medium-term follow-up were reported even with the use of large diameter ceramic heads [37]. These observations were recently confirmed by registry data reporting a ten-year survival of 95.3% of THA with XLPE and a femoral head size > 32 mm.The thickness of XLPE should provide enough fatigue resistance to the components. For this purpose, the design must also be considered.In our experience, we use larger femoral heads in the more active patients when we can select a XLPE liner with a minimum thickness of 5-6 mm, that means in acetabular components with a minimum size of 54 mm [38].In old and low demanding patients, a thinner liner can be used with the aim of improving stability and reduce the risk of dislocation. In such type of patients, stability must be balanced versus wear.(Fig.5)

Figure 5: Intra-operative measurement of acetabular components and liner of a total hip arthroplasty: a) the metal back has a minimum thickness that must be taken into account; b,c) a minimum polyethylene (PE) thickness must be preserved even when selecting large diameter femoral heads; smaller PE can be used in old people or with low demanding d) ceramic liners can be thinner than PE liners.

Breakage of the XLPE liners has been described especially in steep cups with elevated rims and bad locking mechanism [39–41]. To overcome this issue, it is also possible to use XLPE Vit E that reduces oxidation in vivo, with similar wear but improved mechanical strength (the weak point). This treatment showed promising results with very low wear, even for 36 mm heads [42].

METAL ON METAL (MOM) AND METAL-ON-POLYETHYLENE (MOP)

Metal on metal THA has a long history which began in the 1950s and 1960s in the United Kingdom with McKee-Farrar. In the 1980s, small MoM heads (28 mm and 32 mm) by Weber and Semlitsch became quite popular, even if they never gained a major role in the market. Acceptable results are reported with small MoM heads both by registries and clinical studies at medium- to long-term follow- up [43,44]. Unfortunately, due to the high rate of failure and of adverse reactions to metal debris following the MoM big heads introduced in the middle of the 2000s, and despite the early favorable outcome of hip resurfacing, MoM THA is nowadays almost entirely abandoned by surgeons and completely withdrawn from the market by manufacturers, including small heads. In fact, adverse reactions were reported mostly for big heads MoM THA , with specific MoM implant modular design parameters conditioning metal ion release, but also in case of small-head MoM THA. This bearing surface is no longer an option and the issue nowadays is how to follow-up patients implanted with MoM in the past [45]. It is also interesting that there is an increasing concerns on the trunnions with metal heads in Met-PE, but there are no clinical reports on ceramic heads [46,47]. On the other hand, using a ceramic head, CoCr fretting and corrosion from the modular head-neck taper may be mitigated although not completely eliminated [48].

THA is overall a very successful procedure. The long-term survival and satisfaction of patients is linked to the proper bearing surface selection. The surgeon has a responsibility to make a wise choice, based on a comprehensive knowledge of the features of the selected bearing. Actually the trend for bearing option in US[49], [UK3] and Italy[50] is shown in (Fig.6).Registry data, despite evident differences between countries, show an increasing trend of usage of CoXPLE over the last years.

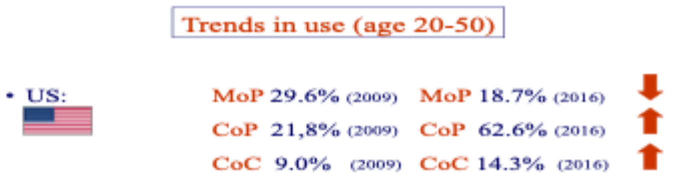

Figure 6: Trend used US, UK and Italy.

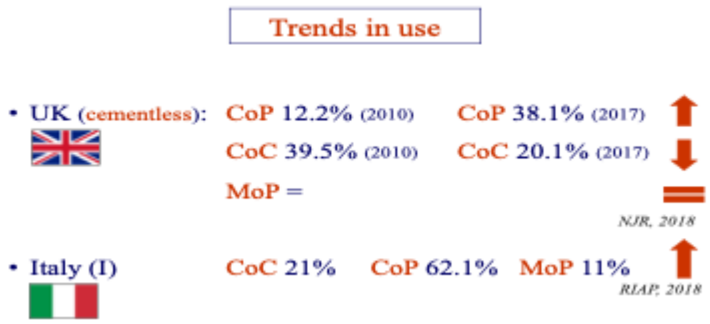

Figure 6: Trend used US, UK and Italy.

CONCLUSION

In conclusion, a comprehensive knowledge of the characteristics, advantages and drawbacks of each bearing surface is essential for surgeons who routinely perform THA. This, along with personal experience, will help in selecting the best coupling for each patient in order to provide the best long-term survivorship of the prosthesis. This allows balancing wear with stability according to the main need and functional requests of the single patients. In our experience, CoC in young and active patients (for the higher wear resistance and biocompatibility) is a good option in a proper metal back. CoXLPE and MoXLPE are a valid option for 'older' patients offering a more 'forgiving' bearing, and good results reported at 15 years. The routine use of ceramic heads makes sense as trunnionosis, even if quite [51] and infrequent (representing between 0.3 and 2% of the causes of revision), can have catastrophic effects on soft tissues. With the widespread use of ceramic heads, we advocate to have ceramic heads at the same price as metal heads by the companies, as price is the only issue. Both CoC and CoXLPE functioned well, with no osteolysis at mean of 17.1 year follow-up. Anyway, surgeons must remember that what makes the difference is not just the material, but the correct surgical technique and handling of the components mainly the positioning of the implant. Moreover, weight and body mass index do not influence the choice of the bearing, whilst in cases with major anatomical deformities, pre-operative high range of movement and soft-tissue laxity, CoC should be used carefully – even if the patient is young.

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