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GENERAL REVIEW

Wear products of total hip arthroplasty: The case of polyethylene

Produits d'usure des arthroplasties totales de hanche : le cas du polyéthylène

P. Massin*, **S. Achour**

Département de chirurgie orthopédique, hôpitaux universitaires Paris Nord Val-de-Seine, site Beaujon, 100, boulevard du General-Leclerc, 92110 Clichy, France

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Summary Among the bearing surfaces involved in a total hip arthroplasty, ultra-high molecular weight polyethylene (UHMWPE) is the weak link. It is submitted to the friction of a harder bearing, producing wear particles, which, in turn, initiate an inflammatory reaction ultimately leading to osteolysis. This kind of bone deterioration sometimes turns out to an aggressive granuloma and may provoke implant loosening. Wear resistance of UHMWPE depends on its molecular weight and crystallinity. Some steps of the manufacturing process were improved to optimize its tribological properties and to slow down degradation resulting from mechanical (abrasion) and chemical (oxidation) phenomena. Its preparation and conservation must be performed in an inert atmosphere, i.e. without ambient oxygen. Its resistance to abrasion depends on its cross-linking degree. Its cross-linking rate was observed to increase proportionally to the irradiation doses, improving its wear resistance. However, its mechanical properties are impaired and moreover, it becomes oxidation sensitive. It is therefore necessary to submit it to a thermal treatment to eliminate free radicals that were produced during irradiation. More recently impregnation by vitamin E, a powerful anti-oxidant product, was proposed to preserve the polymer from in vivo oxidation while maintaining its mechanical properties. We raised the hypothesis that last-generation UHMWPE could offer the same wear resistance as the most performing bearings (ceramic-on-ceramic). Recent clinical results confirm the tribological performance of highly crosslinked UHMWPE in vivo. However, it remains to be seen whether this excellent wear resistance would persist under eccentric load such as edge loading, and if, in the long run, this kind of bearing proves capable of reducing the risk of osteolysis in young and active patients.

* Corresponding author.
E-mail address: philippe.massin@aphp.fr (P. Massin).

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MOTS CLÉS
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Ostéolyse induite par les particules d'usure

Résumé Le polyéthylène de très haut poids moléculaire (UHMWPE) est le point faible du couple de frottement dans l'arthroplastie totale de hanche. Il subit une friction d'une surface sphérique dure qui l'abrase et produit des particules d'usure. Celles-ci induisent une réaction inflammatoire qui aboutit à l'ostéolyse. Ce type d'altération du support osseux peut parfois prendre une allure pseudo-tumorale agressive et conduit au descellement des implants. La résistance à l'usure de l'UHMWPE dépend de son poids moléculaire et de sa cristallinité. Certaines étapes de la préparation du polymère ont été modifiées pour améliorer ses propriétés tribologiques et ralentir sa dégradation qu'elle soit mécanique (abrasion) ou chimique (oxydation). Sa préparation et sa conservation doivent être pratiquées en atmosphère inerte, c'est-à-dire dépourvu d'oxygène. Sa résistance à l'usure dépend du degré de réticulation, qui augmente avec la dose d'irradiation. Cependant, l'irradiation altère ses propriétés mécaniques et le rend sensible à l'oxydation. Il est donc nécessaire de le soumettre à un procédé thermique pour éliminer les radicaux libres produits par l'irradiation. Plus récemment, l'adjonction ou dopage à la vitamine E, puissant anti-oxydant, a été proposée pour préserver le polymère de l'oxydation in vivo tout en maintenant ses propriétés mécaniques. Nous avons émis l'hypothèse que le UHMWPE de dernière génération offrait une résistance à l'usure proche de celle des couples de frottement dur/durs de référence (céramique/céramique). Les résultats cliniques les plus récents confirment les excellentes performances tribologiques du UHMWPE in vivo. Cependant, le comportement de ces nouveaux UHMWPE en positions limites de charge excentrées restent en question, et des études à long terme sont nécessaires pour montrer la diminution du risque d'ostéolyse chez les patients jeunes et actifs.

Introduction

Total hip arthroplasty (THA) provides excellent immediate functional results and therefore represents one of the most efficient operations in the orthopedic surgeon panoply. However, long-term results may have been disappointing and explained its restricted use in young active patients. Like other joints with large range of motion being submitted to cyclic and heavy loading, friction of the bearing surfaces produces wear particles that are susceptible of diffusing in the surrounding soft tissues [1] and also of migrating towards more remote organs [2].

THA could be described as a simple ball joint opposing 2 spherical surfaces (enarthrosis) whose wear depends on several parameters among which the congruency of the bearing surfaces. An optimal congruency results from fine machining but also depends on the intrinsic mechanical properties of each component. In particular, the softer material is expected to mold itself on its harder counterpart, thus optimizing the congruency under load. This phenomenon contributed to polyethylene success when it was articulated against a metallic stainless steel head, as proposed by Charnley et Halley in the late sixties [3]. This kind of bearing is still in use nowadays, because its mechanical and chemical properties were substantially improved by increasing its molecular weight.

Other advantages of this material include a perfect biocompatibility, inducing neither allergy nor immune response as long as its macroscopic integrity is preserved. Unfortunately, this is no more true as soon as microscopic debris are released all around the joint, provoking an inflammatory reaction starting when these particles become phagocytized by macrophages. This reaction finally results in osteolysis, which ultimately, may compromise implant fixation.

Along with refinements of manufacturing processes, other bearings became available for THA, combining hard surfaces for an optimal friction, characterized by very low wear rates (ceramic-on-ceramic). Such materials allowed widening the indications of THA to younger and more active patients [4,5]. Consequently, the use of ultra-high molecular weight polyethylene (UHMWPE) substantially decreased, although it is still the most worldwide used bearing surface in the field of joint arthroplasties. In particular, its resistance to wear was optimized by increasing its crossliking rate.

The question arises as to know whether UHMWPE remains the best choice compared to hard-on-hard bearings. We postulated that modern UHMWPE has gained enough wear resistance to be eligible as a first-choice bearing surface to be used in the arthroplasties of young and active individuals. We therefore investigated 2 questions.

- Was wear potential significantly reduced by new manufacturing techniques?
- Is there still a risk of aggressive osteolysis with modern UHMWPE?

To respond to these interrogations, we first explained the degradation modes of UHMWPE, then the resulting biological and clinical phenomena, and we finally review the methods that are actually available to improve its wear properties.

Modes of degradation

Degradation of UHMWPE depends on its physical and mechanical properties, measured by its molecular weight (average number of monomer per chain) and by its