Wear Debris in Prothesis for Biomaterials

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Résumé :

La technique des remplacements des joints synovial endommagés ou malades représente l'une des plus grandes avancées dans la chirurgie orthopédique du vingtième siècle. Ces remplacements concernent l'épaule, la cheville, le coude, le genou, et la hanche qui occupe une place particulière dans les interventions chirurgicales. Actuellement plusieurs milliers de prothèses de hanche sont remplacées par année et tous les implants se composent d'un ensemble représenté par une cupule couplée avec un cotyle dur, en métal ou en céramique, et un polymère plus mou. Depuis les années 60, le polymère à haute densité (PEHD) domine les applications concernant les surfaces d'appui utilisées dans la chirurgie orthopédique. Cependant la genèse des débris d'usure du PEHD au niveau des surfaces d'appui reste un sérieux problème pour les patients portant les implants de longue durée. Le volume et la morphologie des particules d'usure sont importants pour la détermination de la réponse du corps aux débris et aux effets entraînant le blocage de la mobilité. Cet article présente un examen des types de particules les plus fréquents trouvés dans les biopsies des tissus arrachés des prothèses. En effet, la taille et la quantité de ces des débris sont des facteurs très importants pour une meilleure compréhension des processus d'utilisation dans les joints artificiels. Des particules réelles sont également décrites en cet article.
Mots-clés: Débris d'usure, joints artificiels, méthodologie de séparation.

Abstract :
The total replacement of damaged or diseased synovial joints represents one of the greatest advances in orthopaedic surgery of the 20^{th} century. Whereas replacements are available for the shoulder, ankle, elbow, knee, hip accounts particularly for the most surgical interventions. Currently in the world several thousand hip joints per year are replaced and all the implants consist of a sliding pair represented by a hard counterface, either metal or ceramic, and a softer polymer. Since the early of 1960's, Ultra High Molecular Weight Polyethylene (UHMWPE) became the dominant polymer for bearing surfaces in orthopaedic surgery. However, generation of UHMPWE wear debris from bearing surfaces in patients still the major problem for the long term implants. Both volume and morphology of the wear particles are important to determine the response of the body to debris and subsequent effects on secure fixing. This paper presents a review of the type of particles which are the most frequently, found in biopsies of tissues from explanted prostheses. Indeed, the size and the amount of these debris are very important factors for a better understanding of wear processes in artificial joints. Real wear particles are also described in this paper.

Key-words: *Wear debris, artificial joints, separation methodology*

Introduction:

Wear of materials causes different consequences depending on the type of the system in which it occurs. In engineering systems, wear leads to loss of tolerance, friction, contamination, and so on. In biological systems, wear (and mainly wear debris) elicits an environmental response, determinating the life of the prostheses in the human body. Bio-tribology was a term introduced by Dowson and Wright [1] to cover all aspects of the tribology related to biological systems. Nevertheless, corrosion can also act in synergy with the phenomena of wear because the human body physiological fluids are particularly aggressive even for biomaterials: for example, human blood consists of cells in suspension in a complex liquid, (plasma); this **"**Plasma removed from fibrogen takes the name of serum" is an aired -water solution, with various

organic substances (glucids, lipids, proteins). However, pH can decrease to approximately 5.2 in recently implanted tissues and returns to its initial value two weeks later [3]. But, in theory, this brutal pH change of the body fluids is not associated to a significant corrosion of the biomaterial.
The "gold standards" for the Total Hip Replacement (THR) or for the Total Knee replacement (TKN) are the followings [4]: Excellent biocompatibility -*Good mechanical performance* -*Chemical and hydrothermal stability* -*Superior wear properties, i.e. low wear* -*No ion release*, no allergic responses. Another aspect of material selection which needs careful attention is the possibility that the wear debris might lead to short or long term tissue reactions: Polyethylene particles, mainly in the sub-micron range [5,6], have been implicated in the loosening process. The development of osteolysis which disrupts the integrity of the implant– cement-bone interfaces [7, 8] can be resulted. Table 2 shows the different wear rate versus the head/cup combination [9] Moreover, shape and surface morphology of wear particles contain information about wear processes involved in their formation [10,11]. This paper is devoted to a real case and shows the diverse techniques and methods used.

Materials and methods:

2.1 Periprosthetic tissues

Figure 1: Macroscopic appearance of periprosthetic tissue in a formaldehyde solution (case of granuloma).

2.2 Isolation of wear particles [12,13,14,15]

2.3 Characterization of particles – SEM and ESEM

Ion	Concentration / mM
Na +	142,0
K	5
Mg 2+	1,5
Ca 2+	2,5
Cl -	103,0
HCO -3	27,0
HPO 4 2-	1,0
SO 4 2-	0,5

Head /Cup	Wear rate
Metal-on-PE	0.2 mm per year and more
Ceramic-on-PE	0.1 mm per year
Ceramic-on-ceramic	0.005 mm per year

TABLE 1: Ionic composition of the human blood plasma [2].
TABLE 2: In vivo wear rates (linear wear) [9]

3. Experimental Results

Our analysis revealed finally several kinds in nature of wear particles: organic debris, bony metallic and polyethylene.
The proportion of polyethylene debris was more important than the others. Figures 2 to 5 show typical particles recovered in this biopsy and identified by the techniques described

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3.1 Organic particles

Different particles with an organic origin were collected. Figure 2(a) shows a soft tissue particle, probably a synovial tissue fragment. Figure 2(b) shows typical bony debris with a flake shape. The debris size range is generally upper than 20 µm long, but very little debris can be also observed.

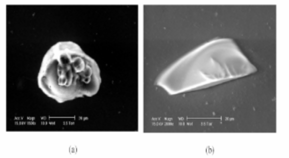
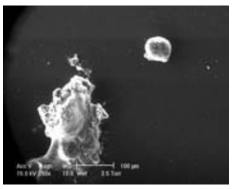


Figure 2: Scanning Electron Microscope picture of (a) soft tissue and (b) osseous particle [16]

3.2 Bony -metallic particles

Figures 3 and 4 show particles which are both bony and metallic: the spectral peaks of phosphorus and calcium are detected however the peaks of iron and chromium are also present. The peaks of phosphorus and calcium are very distinctive (figure (a)) but for the metallic elements (figure (b)) a magnification of the x-ray patern is necessary. No cobalt was detected with the sensitivity of the x-ray analysis. Laffargue et al. [7] concluded alloys containing cobalt, chromium (and also nickel if present) corrode in vivo and release metal ions in biological fluids as well as in implant surrounding tissue. No pure metallic particle was observed in our case. The debris shape is compact chunks with a "corroded" surface and their size can reach several hundred µm in length.



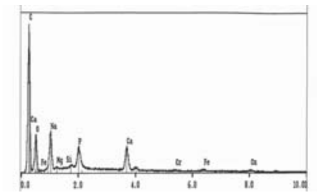


Figure 3: Scanning Electron Microscope pictures of bony-metallic debris [16] Figure 4: SEM X-ray analysis of a bony-metallic debris (a) and details (b) [16].

3.3 Polyethylene particles

Polyethylene particles have often shred's form. They have a variety of sizes, ranging in to 1µm or less to 10 µm and up in length, probably according to different wear processes. Figure 5 shows two examples of recovered debris.

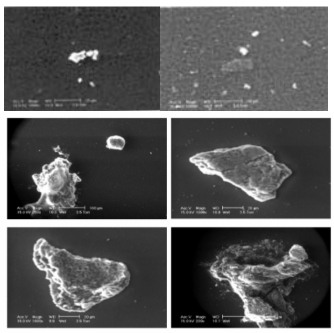


Figure 5: Environmental Scanning Electron Microscope picture of polyethylene debris [16].

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4. Conclusion:
In the present investigation work, the feasability for extracting wear debris from an aspectic tissue of an old implanted person was demonstrated. The wear particles, generated essentially by the cup/femoral head friction pair, were analysed. Different points can be underlined in this case: - the proposed debris isolation procedure was efficient and easy to apply,
- the microscopic observations of wear particles after their isolation by filtration showed a wide range of particles from diverse origins. Indeed, one of the still unresolved problems in tribology is relationship between the numerical characterization of wear particle morphology (aspect ratio, shape factor, roundness…) and the mechanistic factors of wear. Hence, recent research efforts have enabled the development of numerical descriptors, the application of computer technology and the image analysis techniques which permit the assessment of particle morphology. The development of numerical descriptors seems to be the best way of overcoming these deficiencies.

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