Degree of the Polyethylene Component Wear – a Predictive Factor for the Outcome of Total Hip Arthroplasty

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The purpose of this paper is a radiological evaluation of the prosthetic polyethylene component wear in time (years), a quantification of this wear depending on the different types of prostheses and a correlation between the degree of wear and the radiological signs of deterioration of the periprosthetic bone structures, resulting in mobilization of the prosthetic components (loosening).

Keywords: polyethylene, hip prosthesis, particle disease, loosening

In patients suffering of osteoarthritis of the hip (a degenerative condition of the hip that finally leads to anatomical and functional impairment of the joint), the only efficient treatment in advanced stages of the disease is the surgical replacement of the joint with a total hip prosthesis. Unfortunately, despite improving the composition of the materials from which these prostheses are made of, as well as their design, they remain functional only for a limited period of time, on one hand due to material wear, and on the other hand due to the loss of attachment to the surrounding bone. Depending on the manner in which the prosthetic components are fixed to the bone, the prostheses can be cemented, when an acrylic cement is used, or uncemented, when the fixation is performed by "forceingly" introducing the prosthetic parts into the anatomic bony articular structures, previously adjusted to the appropriate size. However, the movement coupling of hip prostheses can be made of various materials: polyethylene, metal or ceramics. At present, at a global level, the majority of hip prostheses implanted contain polyethylene, which has been proven to release submicronic particles during its functioning, responsible for altering the quality of the periprosthetic bone (particle desease). This results in loss of appropriate fixation of the prosthetic components, reinstatement of hip pain and functional impairment and the need for a new surgery, to replace the prosthesis with a revision one. A lot of recent material composition and tribology research is aimed to decrease this phenomenon, trying to prolonge the survival rate of these articular prostheses.

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Experimental part

Material and methods

Our study was conducted on a group of 82 patients (96 hips, as 16 patients required successive, bilateral surgery) who underwent primary total hip arthroplasty (cemented in 58 cases and uncemented in 38) in a period of time between 2006-2008. The cemented hip prostheses were manufactured by Biomet (Biomet Inc., Warsaw, Indiana, USA) and display 3 components: an all-polyethylene acetabular component (cup), made of Ultra-High-Molecular-Weight-Polyethylene (UHMWPE) with a radiopaque ring made of titanium alloy, presenting grooved rings, parallel in equatorial and longitudinal directions, with an inner diameter of 28 mm; an universal (right, left) stainless steel femoral component (stem) made of a CoCr alloy, straight, double-cone shaped, without a collar, with medio-lateral support (need not distal centering), with a surface specially designed to achieve perfect contact between metal and cement, sterilised with Gamma rays in inert gas environment (Argon) and a 28 mm diameter femoral head made out of the same alloy.

The uncemented hip prostheses were manufactured by Zimmer (Zimmer Inc., Warsaw, Indiana, USA) and display 4 components: A Trilogy type press-fit acetabular component made up of Titanium alloy covered with Titanium metallic fiber mesh, with a complete hemispheric shape for a better contact with the bone and primary stabilization, with a porous surface due to the Titanium fibres; it achieves complete congruence between the metal back and the polyethylene cup, reducing movement at the interface level due to a locking ring, which presents antirotation peaks; the primary fixation of the cup (made of UHMWPE) is of a press-fit type and secures it agains micromovements and transverse (sharing) forces; a Versys femoral component (stem) made out of Titanium alloy, a straight rod, with no collar, with metaphyseal support, universal left/right, with a trapezoid section at the proximal end with antirotation effect, and a cone-shaped distal end that prevents contact with the cortex and distal transmission of the weight bearing forces, and reduced geometry of the neck to increase the degree of mobility; the surface of the stem is covered with a Titanium fiber net in the proximal third for secondary stabilization, sandblasted in its middle third for additional fixation and polished in the distal third to avoid the risk of thigh pain); a 28 mm stainless steel CoCr alloy femoral head.

Patients mean age at the time of the operation was 66.8 years, with limits varying between 31 and 84 years. Sex distribution was: 47 females and 35 males, with a 1.34 ratio in favour of the females. Average postoperative follow-up period was 5.6 years, with limits between 6 years and 3 months and 4 years and 2 months.

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All prostheses were implanted by the first of this study's authors, using the same surgical technique, meaning transgluteal lateral approach.

Standard anteroposterior pelvis x-rays, using a non-portable X-ray machine were performed in all patients at 6 weeks after surgery, and afterwards on a yearly basis, during the follow-up visits. The degree of the polyethylene component wear was measured manually, with the help of concentric templates, and the degree of loosening was measured by means of a protractor and a millimetre calibrated ruler

The degree of the polyethylene component wear was estimated according to the Livermore technique [1], by comparing the radiographs performed at 6 weeks postoperatively with the most recent one available at the moment when the study was completed.

As the polyethylene component wear is considered cylindrical, the volume of lost plastic material can be calculated by multiplying the radius of the metallic femoral head by the dimension in mm (height) of the superior pole wear of the cup. The annual rate of volume wear is calculated by dividing the total volume of lost material by the number of years passed since the prosthesis was implanted.

The acetabular component was considered migrated when it moved with more than 5 mm or changed its tilt by more than 10 degrees.

Results and discussions

The average degree of linear wear (height-wise) of polyethylene was 0.72 +/- 0.32 mm, with limits between 0 and 2 mm for metal back uncemented cups and 0.55 +/ - 0.30 mm with limits between 0 and 3 mm for all-polyethylene cemented cups ($p<0.05$). The volume polyethylene wear in the first category was in average 411.54 +/- 187.71 cubic mm, with limits between 0 and 1200 cubic mm, while in the second category in average of 330.28 +/- 172.37 cubic mm, with limits between 0 and 1600 cubic mm ($p<0.05$).

The yearly average rate of linear wear of polyethylene in metal back uncemented cups was 0.12+/-0.05 mm, with limits between 0 and 0.3 mm, while that of all-polyethylene ones was 0.08+/-0.04, with limits between 0 and 0.4 mm ($p<0.05$). Yearly volume wear average rate was 71.24 +/- 35.42 cubic mm, with limits between 0 and 200 cubic mm, in the first category, and 49.38 +/- 33.87 cubic mm, with limits between 0 and 230 cubic mm in the second category ($p<0.05$).

Acetabular migration was recorded in 5 cases (13.15%), for metal back cups, and only in 2 cases (3.44%) for all-polyethylene cups ($p<0.05$).

The degree of wear varied proportionally with the patient age at the time of surgery, and did not depend on the patient's height, gender, aetiology of the osteoarthritis or thickness of the cup. In patients with uncemented total hip prostheses the mean annual volume wear rate was 78.14+/- 34.82 cubic mm for patients under the age of 40 and 57.54 +/- 32.76 cubic mm for those of 40 years of age and over ($p>0.05$).

Polyethylene is a polyolefin produced by polymerizing the olefin ethylene. The UHMWP has very long chains, with a molecular weight between 3.1 and 5.67 million Daltons and which all have parallel orientation. Each UHMWPE molecule contains 100,000 to 250,000 monomer units per molecule (the standard high density polyethylene contains 700 to 1,800 monomers). Molecules are bonded together by Van der Waals bonds. Each bond of this type is relatively weak, but, because the molecules are extremely long, the cumulative Van der Waals forces between molecules are very strong. That's why UHMWPE is very resistant to mechanical loads and to abrasion.

It does not contain hydroxylic, carboxylic, amine, amide or esters groups and, this way, it is resistant to acids and bases, water and is biocompatible. Its coefficient of friction is very low, like polytetrafluoroethylene (usually known as Teflon).

UHMWPE is produced from ethylene (the monomer is polymerized under metallocene catalyst).

Polyethylene (in the form of high density polyethylene) was used in the first hip prosthesis introduced and used by Sir John Charnley in November 1962 [2] (he tried Teflon before that, but the results were not the ones expected). In time the UHMWPE proved to be significantly superior to the high density form and is widely used today. In the late nineties the highly cross-linked UHMWPE was introduced. The UHMWPE is cross-linked by exposure to gamma or electron beam radiation (50–105 kGy). The oxidation resistance of this polymer is enhanced by thermal procedures after cross-linkage.

Initial research focused on studying the quality of the cement (fig. 1), the cementing techniques and of the positioning of the prosthetic components, in order to explain the loosening phenomenon which was occuring at a time after surgery. Subsequently, it was observed that the mobilization of the prosthetic components is due to an osteolysis process generated by the release of microparticles, especially of polyethylene , that are formed during the functioning of the prosthesis and reach the periprosthetic interface. This special condition, called "particle disease", induces a reactive response from the organism and leads to destruction (osteolysis) of the bone that supports the prosthesis, both in case of cemented or uncemented types [3].

Some of the first studies regarding cemented prostheses and their outcome belong to Charnley and Cupric [4] and afterwards to Harris et al. [5].

Polyethylene particles are generated through an abrasion phenomenon, which takes place at the level of the movement surface between the femoral head and the polyethylene cup, and are of submicronic dimension (most of them are under 0.3-0.5 micrometers). They spread in very large numbers in the soft periprosthetic tissues (the so-called "prosthesis chamber") and manage to infiltrate the interface between the prosthetic components and the bone. This process is faster and more intense in the case of uncemented prostheses (fig. 2), where such microscopic access points remain after implantation. This explains why osteolysis can sometimes develop directly at the tip of the femoral stem, or at the upper pole of the acetabular cup. Completely different from what was initially believed, that

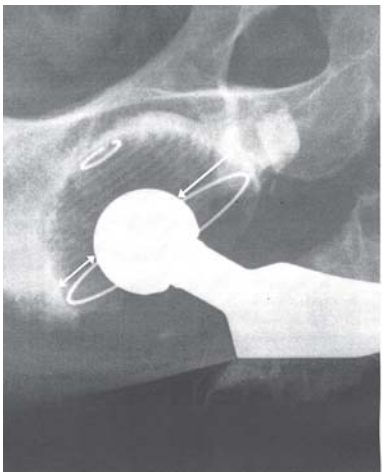

Fig. 1. Worn polyethylene acetabular cup – antero-posterior X-ray view of a cemented total hip prosthesis

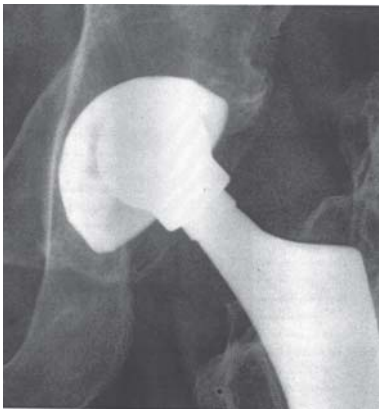

Fig. 2. Worn polyethylene acetabular cup – antero-posterior X-ray view of a uncemented total hip prosthesis

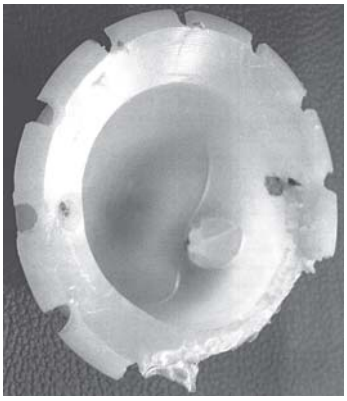

Fig. 3. Polyethylene wear in an acetabular cup – extracted at revision

Fig. 4. Worn polyethylene acetabular cup – extracted at revision

the cement is responsible for the osteolysis phenomenon, the importance of "sealing" the periprosthetic space from particle access was mentioned, and so, the second or third generation cementing technique is now considered to actually be a protecting factor against particle disease.

Once released on the periprosthetic bone surface, these particles are considered as foreign bodies for the surounding tissues and generate an inflammatory response, in which the main mechanism is that of macrophage migration. Histological studies have shown that, beside these, the periprosthetic tissues also contain other bone resorption factors, such as: osteoclasts, enzymes, cytokines etc. In general, the number of macrophages present on the microscopic field when examining the periprosthetic tissue is directly proportional to the degree of osteolysis.

Polyethylene wear (fig. 3) and the development of osteolysis are initially asymptomatic and evolve progressively. When pain occurs, due to loosening of the prosthetic components, we find ourselves in front of a very advanced degree of osteolysis, which compromises the bone stock, needing to replace the prosthetic components (revision). This is why it is very important for us to diagnose these changes early in the process in order to limit the loss of bone stock. One of the most valuable diagnostic methods for these lesions is periodical radiological evaluation and measurements of polyethylene wear and prosthetic components mobilization.

Some of the first measurements of the acetabular cup wear were performed by Charnley and Cupic on Teflon cups [4]. At that time (1973), they showed that measurements performed by the same person, with the same non-portable X-ray machine in anteroposterior view, in the same technical conditions, are probably the most accurate way of quantifying the degree of polyethylene wear. Livermore et al. [1] described a simple and low-cost measuring method that uses a transparent "template" with concentric circles, a pair of compasses and a beam compass. They made parallel measurings, radiologically and then directly, after replacing the prosthetic components and recorded a minimal difference of approximately 0.075 mm, which proves this radiological method to be a very accurate one. Anteroposterior view x-ray examination allows only a measurement in the frontal aspect, but if the polyethylene wear is concentric, the volume wear can be easily calculated considering the dimensions of the prosthetic femoral head .

The degree of polyethylene wear (fig. 4) is influenced by a number of factors: dimension (diameter) of the femoral head and the material from which it is made of, the hardness of polyethylene, which usually results from the degree of polymerization and the chemical composition (all prostheses included in our study contained only UHMWP), whether or not the cup was all-polyethylene (all cemented prostheses included in the study) or had a metal back hosting a polyethylene inset (all uncemented prosthesis cases). Also, the cementing technique, as we have previously mentioned, plays an important role in blocking the access of the polyethylene particles to the prosthesis-bone interface.

The age at which the prosthesis was implanted can represent a predictive factor for the intensity of osteolysis [4]. The level of physical activity in young patients is decidedly higher than in elders, which leads to the production of a higher quantity of particles, which ultimately determine early mobilization of the prosthetic components.

Conclusions

Early detection of the radiological signs of polyethylene wear and loosening of the prosthetic components is a very important predictive factor for the long-term results of hip replacement, and also for the immediate instatement of an appropriate treatment. Clinical signs, such as pain and functional impairment of the hip usually occur late, when the degree of osteolysis is high enough to compromise the periprosthetic bone stock. At the time when osteolysis and migration of the prosthetic components are noticed, regardless whether the patient is in the asymptomatic phase, the extraction of the old prosthesis, treatment of the osteolytic lesions and reimplantation of a new prosthesis (revision) must be performed.

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