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Polyethylene particles in joint fluid and osteolysis in revision total knee arthroplasty

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ABSTRACT

Background: One of the most frequent reasons for total knee arthroplasty late failure is osteolysis. It has been related to foreign body reaction to polyethylene particles.
The aim of this study is to analyse the number, size and morphology of polyethylene particles in synovial fluid in total knee arthroplasty revision and correlate them to the pathology and the degree of osteolysis.
Methods: Synovial fluid was obtained in 12 patients before the revision total knee arthroplasty. Polyethylene particles were isolated and analysed through scanning electron microscopy. Samples of synovial tissue were analysed with optical microscopy while considering the parameters of particles and histiocytic infiltration. Osteolysis was analysed with plain radiography and the macroscopic aspect during surgery.
Results: The statistical analysis showed a significant correlation between a high concentration of polyethylene particles in synovial fluid and a high degree of osteolysis. The concentration of particles in synovial fluid also showed a significant correlation with a high degree of particles and histiocytes in the histological analysis. There was a relationship between the size of particles and the degree of osteolysis. No relationship was found between the shape of the particles and the histological findings or the degree of osteolysis.
Conclusions: In an "in vivo" TKA scenario, the presence of a high concentration of polyethylene particles in the synovial fluid seems to be the cause of a highly active foreign body histological reaction, with an increased number of histiocytes, which seems to be the cause of a significant degree of osteolysis around the implant.

1. Introduction

Aseptic loosening secondary to osteolysis is the main cause for total knee arthroplasty (TKA) failure in the long-term period [1]. Periprosthetic osteolysis has been related to foreign body reaction to polyethylene particles, which are in the knee joint fluid due to material fatigue mechanism from the insert [2].

When polyethylene particles are phagocytised by macrophages and giant cells, many cytokines are secreted. Some interleukins (IL), as IL-1β, IL-6 and alpha-necrosis tumoral factor cause inflammation and activate osteoclasts, the main cells responsible for osteolysis [3–5]. Moreover, cytokines inhibit bone formation by osteoblasts [6].

The size of the polyethylene particles is an important issue as those between 1 and 10 μm bring about greater biological activity and more osteolysis than particles greater than 10 μm, which cannot be phagocytised and cause less of an inflammatory reaction [7].

Over the last decade, some studies have described the technique, which permits studying polyethylene wear and its effects "in vivo", for joint fluid analysis of polyethylene particles [8].

The main aim of this study was to analyse the number, size and shape of polyethylene particles in knee synovial fluid in TKA that are being revised and to analyse the relationship between these particles in joint fluid, radiological osteolysis around TKA. The findings during revision surgery and the histological findings in the tissues around the implant were also analysed.

2. Material and methods

A prospective study was designed. The inclusion criteria were patients with an indication for a first revision TKA after a cruciate-retaining (CR) or a posterior-stabilised (PS) primary TKA that had been implanted at least 1 year before the revision. The exclusion criteria were the presence of an infection and the impossibility of obtaining at least 3 ml of synovial fluid previous to revision surgery. In all cases, the revision surgery was done by the same surgeon (PH).

The preoperative variables analysed were: age, gender, weight, height, body mass index (BMI), femoro-tibial angle (FTA) measured in a long weight-bearing X-ray, time between primary and revision surgeries, cause of revision, severity of radiographic osteolysis (quantified as none, mild, moderate or severe), and the type of primary TKA.

Twelve patients were included in the study. The mean age was 70.6 (61–90) years. There were two males and 10 females. The mean weight was 72.83 (62–92) kg, and the mean BMI was 29.99 (24.21–41.44) kg/m^2. Nine patients had a normal FTA, two patients had more than 3 degrees of valgus and one patient showed more than 3

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degrees of varus. The reason for the revision was aseptic loosening in five patients (41.7%), painful arthroplasty with a scintigraphy suggesting loosening in three patients (25%), instability in two patients (16.7%), knee stiffness in one case (8.3%) and polyethylene wear in another patient (8.3%).

Time elapsed between primary and revision surgeries averaged 5.08 years (2–12). Fifty percent of the primary TKAs were PS and 50% were CR. The FTA was measured by the same person (IP) in a preoperative digitalised full-length X-ray with the iPACS, software version 5.0. The radiographic osteolysis was measured prior to revision surgery by the same person in all cases (PH) [9].

In all cases, an arthrocentesis in sterile conditions was done immediately before revision TKA surgery and the maximum possible quantity of synovial fluid was aspirated. The average volume of synovial fluid was 14.08 (3–50) ml. During revision surgery, tissue samples of synovial tissue and periprosthetic membranes were taken and sent to the pathology laboratory. These samples were analysed by the same person (NJ) who measured the quantity of polyethylene particles in the samples and the degree of histiocytic infiltration with a modification of the Mirra et al. grading scale [3,10,11] (Fig. 1). Macroscopic osteolysis was graded as none, mild, moderate or severe by the surgeon during surgery.

Other variables analysed were the addition of radiographic and intraoperative osteolysis and the addition of histiocytic infiltration and the quantity of particles in the tissue sample.

The samples of synovial fluid, after identification, were preserved in a sterile tube in a freezer at −20 °C until the day of processing these samples in the following weeks. The samples were processed by the same person (IP) following the technique described by Minoda et al. [8]. It consists in the digestion of the sample in sodium hydroxide at 65 °C for 12 h and the application to a sucrose-density gradient in a 14 ml tube which is ultra-centrifuged at 28,000 rpm for 3 h at 4 °C. The highest level of the tube is applied to an isopropanolol–water density gradient in a 40 ml tube, which is also ultracentrifuged at 28,000 rpm for 1 h at 20 °C to group the polyethylene particles. The interface line is filtered through a 0.1 μm polycarbonate filter to retain the polyethylene particles. This filter is attached to a Petri plate.

In the scanning electron microscope (SEM) department, the filter is set on a brass layer and coated with a gold layer of 40 nm for SEM analysis (Quanta 200 FEI, Co.). In the SEM analysis, 10 random 10,000 augments fields were studied by the same person (EP). If there was a doubt about the composition of a particle, a study with energy-dispersive spectrometry (EDS) was performed so as to confirm that it was a polyethylene and not a contaminant particle. In each random field, the number, size and shape of the particles were analysed (Fig. 2). With that data, we found out the polyethylene particles concentration per ml of synovial fluid and the total quantity of particles in each patient.

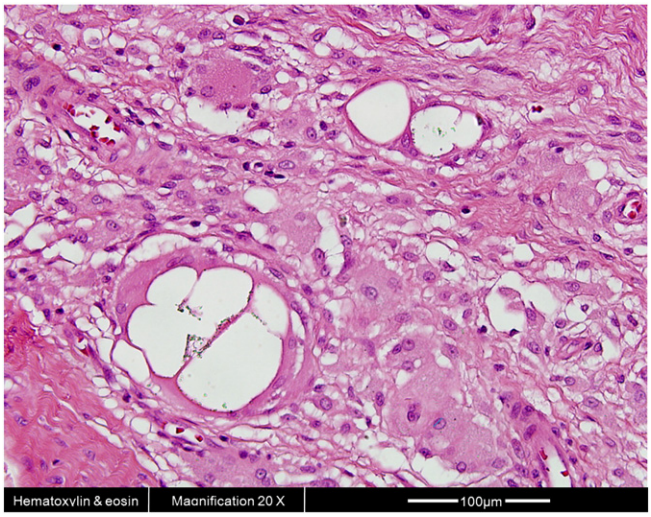

Fig. 1. Microscopic analysis of synovial tissue: moderate concentration of histiocytes with focal foreign body reaction of giant cells and polyethylene particles (hematoxylin and eosin, original magnification ×20).

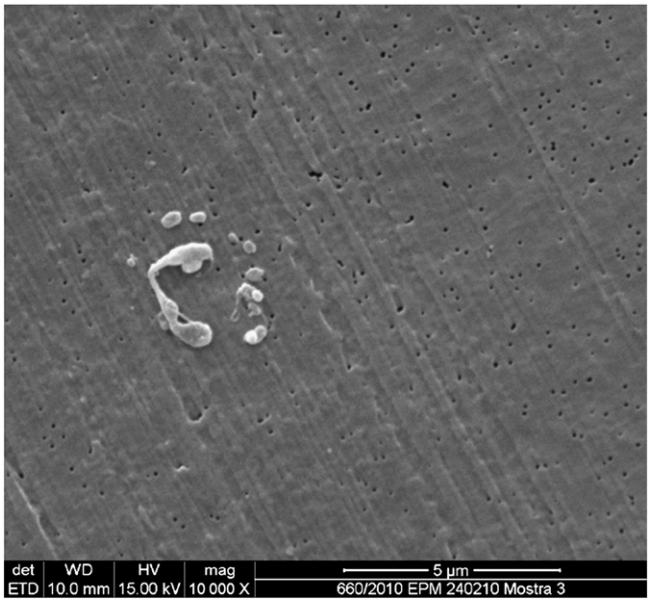

Fig. 2. Polyethylene particles of different sizes and shapes (scanning electron microscope ×10,000).

2.1. Statistical analysis

Data were analysed using SPSS for Windows version 17.0 (SPSS Inc., Chicago, IL, USA). For the statistical correlations of the studied variables, the Spearman's rank correlation coefficient rho was used. Statistical significance was set at a p value of <0.05.

3. Results

In the preoperative X-rays, osteolysis was graded as none in six patients, mild in zero cases, moderate in two and severe in four patients.

In the intraoperative assessment, osteolysis was graded as none in five patients, mild in two cases, moderate in one case and severe in four patients.

The pathological study of the samples of the joint membranes showed six cases with no polyethylene particles, one patient with a low number of particles, three cases with moderate and two cases with a high number of particles. In these samples, there were no cases without histiocyte infiltration. It was mild in four cases with isolated histiocytes. There were five moderate cases with few groups of histiocytes and three severe cases with many groups of histiocytes.

The electron microscope analysis of the processed synovial fluid showed polyethylene particles in different concentrations in all samples, an average concentration of particles that was $1.55 \pm 1.34 \times 10^6$ particles/ml and the total average of polyethylene particles in the samples was $16.9 \pm 10.58 \times 10^6$. The percentage of particles greater than 1 μm was 19.4%, and the analysis of the shape showed that 27.4% of the particles were not round.

The statistical analysis showed a significant correlation between a higher concentration of polyethylene particles in synovial fluid and a higher degree of osteolysis assessed intraoperatively or the addition of both radiological and intraoperative osteolysis. The concentration of particles in synovial fluid also showed a significant correlation with a higher degree of particles in the histological analysis or the addition of particles and histiocytes in the tissue samples (Table 1).

Both, a greater histiocyte infiltration in the tissue and a higher number of polyethylene particles in the tissue samples were significantly correlated with a higher osteolysis assessed both in the preoperative X-rays and in the intraoperative macroscopic aspect of the bone (Table 2).

When analysing the size of the particles, there was a positive correlation between a higher percentage of particles greater than 1 μm and greater osteolysis both in the radiological and in the intraoperative assessment.

No relationship was found between the shape of the particles (percentage of round particles) and the histological findings or the degree of osteolysis.