The Journal of Arthroplasty 28 (2013) 838–841

Contents lists available at SciVerse ScienceDirect

The Journal of Arthroplasty

journal homepage: www.arthroplastyjournal.org

Ceramic Debris in Hip Prosthesis: Correlation Between Synovial Fluid and Joint Capsule

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ARTICLE INFO

Article history:
Received 21 August 2012
Accepted 16 January 2013

Keywords:
synovial fluid
joint capsule
ceramic particles
hip prosthesis

ABSTRACT

Detection of ceramic particles in synovial fluids allows early diagnosis of ceramic damage, but there is no evidence of a relationship between ceramic debris in the articular space and in the joint capsule. The aim of the present study is to verify if the particles isolated in the synovial fluid are comparable with those stored in the capsular tissue. Twenty-one patients were enrolled. Both synovial fluid and capsular samples were collected during revision surgery and ceramic particles were isolated and analyzed by scanning electron microscopy and energy-dispersive X-ray microanalysis. It resulted a significant correlation between the samples couples (18 out of 21). This study confirms that the synovial fluid analysis can give a clear definition of the presence of particles in the joint capsule.

Ceramic bearings were introduced in total hip arthroplasty (THA) to reduce wear and increase long-term prosthesis survival. They are harder, more scratch resistant and more hydrophilic than other bearing couples, resulting in reduced wear and particle spreading in the surrounding tissue. Although ceramic wear is usually limited [1,2], a large amount of debris is sometimes observed. This happens when damage occurs at the rim of the liner or when the head is fractured. While in the case of ceramic head fractures, clinical and radiological signs are clear, and patients usually present with unpaired walking [3], in the case of ceramic liner fractures the signs could easily remain undetected [4] and the wear particles produced can play an important role for the subsequent longevity of the THA. In fact, in addition to tissue's biological responses the presence of ceramic particles increases the damage by a mechanism known as third body wear [5,6].

In order to avoid the wide spread of ceramic particles in the periarticular space and the phenomena above described, early recognition of clinical signs of ceramic damage is paramount. The more conventional techniques, like radiographs or computed axial tomography (CT scan), are not able to detect small ceramic particles and therefore, they cannot provide an early diagnosis of ceramic fracture.

Synovial fluid analysis, a slightly less invasive practice than surgery, has been previously proposed as diagnostic test for early detection of ceramic fracture [7].

This diagnostic method has shown a correlation between the presence of ceramic particles in the synovial fluid and a damage of the components [8]; however, it did not investigate the correlation between the presence of particles in the synovial fluid and their presence also in the tissues. To date there are no other studies that have determined if the particles or a fraction of them are stored in the joint spaces.

Therefore we believe that it would be interesting to verify the presence of a selective phagocytosis mechanism of ceramic debris by synoviocytes, based on particles size, since such particles are also found unmodified in the intercellular spaces [17].

The aim of this study is therefore to verify if the situation found in the synovial fluid mirrors what is observed in the tissues, in order to be able to use the fluid analysis when the indication for reimplant is doubtful.

Patients and Methods

After the approval by the institutional review board and the informed consent form was signed by each patient, twenty-one patients implanted with an uncemented cer-cer hip prosthesis were selected for this retrospective and observational study; a synovial fluid and a joint capsule sample were collected for each patient during revision.

Revision was planned because clinical and radiographic signs, together with a previous analysis of the synovial fluid, were strongly indicative for ceramic component damage. Seventeen out of twenty-one patients were suffering from noisy hip, two from recurrent dislocation and two patients from cup or stem loosening respectively.

The Conflict of Interest statement associated with this article can be found at http://dx.doi.org/10.1016/j.arth.2013.01.019.

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0883-5403/2805-0025$36.00/0 – see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.arth.2013.01.019

Demographic data of patients are shown in Table 1. The mean age at surgery was 53 years with a male/female ratio of 8/13. Time between implant and revision was variable, ranging from 5 to 143 months, while time between symptoms occurrence and revision ranged from 1 to 104 months. Biolox forte was the main material used for the head and the insert, and the most frequent head diameter was 28 mm.

Briefly, joint capsule samples were paraffin-embedded and sliced in order to obtain 2 or 3 tissue sections each (20 μm thickness). The slices were placed directly onto the glossy side of the polycarbonate filter (0,2 μm pore size) and released from surrounding excess paraffin with 600 μl of warm Solvent plus (Carlo Erba, Milano, Italy), previously heated at about 40 °C. Tissue slices were then rehydrated with a decreasing scale of alcohol (100%, 80%, 50%). Proteins and all organic components were then digested by at least three subsequent additions of sodium hypochlorite (Sigma Aldrichs, St Luis, MO, USA). Filters were then washed with distilled water and air dried.

Two hundred microliters of synovial fluid were placed directly on the filter, and digested with hypochlorite, following the same procedure [9].

Two or three paraffin sections without tissue were digested on the filter with the same procedure and were used as blanks.

Filters were then mounted on SEM holders by bi-adhesive tape, gold sputtered and examined with a Cambridge Stereoscan 200 electron microscope operated at 20 kV. Micrographs were taken at 10,000 × magnification. Quantification was defined by 20 fields capturing 90 micron [2] each, representing all the regions of the filter. The particles were counted, their major diameter measured and their chemical composition was verified by Energy Dispersive X-ray microanalysis; analysis was performed at 25 mm WD with an Oxford INCA Energy 200 apparatus.

The amount and the size of ceramic particles were then scored for each sample by two operators separately. The Score for the grading of ceramic damage has been previously validated [8].

All results were matching and were classified in three levels: physiological, mild and strong according to Stea et al [8] as shown in Table 2.

Statistical Analysis

The correlation between the results obtained in the synovial fluid samples and in the tissue samples was evaluated applying the Pearson test.

Results

Each sample was classified according to the level of positivity depending on the quantity and size of wear particles (Table 2).

On the whole, 5 cases of physiological, 3 cases of mild and 13 cases of strong positivity were found in synovial fluids. In the corresponding joint capsule samples 5 cases of physiological, 2 cases of mild and 14 cases of strong positivity were found (Table 3).

In 18 out of 21 patients the presence of ceramic wear was similar for both quantity and size in the two different samples, with a significant correlation (correlation 0.703, Pearson test).

Three patients out of the 21 showed no correlation between synovial fluid and capsule (patients 6, 8 and 9). In patient 6 the tissue level of ceramic particles was lower than the fluid level, while the opposite was found in patients 8 and 9.

Finally the blank samples analysis has shown the absence of the debris.

Discussion

The present study aimed at verifying if ceramic particles isolated from the synovial fluid are comparable to particles stored in the joint capsule.

Quantity and size of foreign particles originating from an articular implant such as a THA can strongly influence its success. It is well known that the large amount of polyethylene wear particles produced in the 'soft-bearings' are strictly linked to osteolysis [10], a problem that has only partially been solved by the introduction of cross-linked polyethylene [11,12].

The phenomenon of periprosthetic osteolysis, although less destructive and less common in the hard bearings, like metal-on-metal and ceramic-on-ceramic, can however occur.

The problems caused by metal-on-metal coupling are mainly connected to the release of ions and of particles from either the bearing or the taper junction, while for cer-cer coupling, object of the present study, the production of particles is the main issue.

Ceramic particles do not show strong ability to induce osteoclast differentiation in vitro [13], but their presence is a potential mechanical threat [14].

The amount of particles produced by wear and tear in a well functioning cer-cer coupling is very low, as demonstrated by simulation

Table 1
Demographic Data of Patients Enrolled in the Study.

Patient Number	Gender	Age at Surgery	Material Liner/Head	Head Diameter (mm)	Time Between Primary Surgery and Revision (Months)	Time Between Onset of Symptoms and Revision (Months)	Cause for Revision
1	F	44	Biolox forte/Biolox forte	32	28	3	Noise due to fracture of the modular neck
2	M	28	Biolox delta/Biolox delta	36	32	1	Pain and noise
3	F	65	Biolox delta/Biolox forte	36	22	3	Cup loosening
4	M	61	Biolox delta/Biolox delta	32	6	4	Recurrent dislocation
5	M	45	Biolox forte/Biolox forte	36	39	1	Noise due to rim damage
6	M	53	Biolox forte/Biolox forte	36	9	8	Noise due to fracture of the liner dome
7	F	60	Biolox delta/Biolox delta	36	34	6	Impingement and noise
8	M	55	Biolox forte/Biolox forte	32	6	3	Stem loosening
9	M	64	Biolox forte/Biolox forte	28	5	4	Recurrent dislocation
10	F	53	Biolox forte/Biolox forte	28	46	2	Pain and noise due to rim damage
11	F	60	Biolox forte/Biolox forte	28	34	21	Pain and noise due to rim damage
12	F	54	Biolox forte/Biolox forte	28	107	104	Pain and noise due to rim damage
13	F	60	Biolox forte/Biolox forte	28	91	4	Pain and noise due to rim damage
14	F	39	Biolox forte/Biolox forte	28	45	4	Noise and recurrent dislocation
15	F	56	Biolox forte/Biolox forte	28	28	2	Noise and impingement
16	F	52	Biolox forte/Biolox forte	28	96	10	Pain and noise due to rim damage
17	F	39	Biolox forte/Biolox forte	28	76	8	Pain and noise due to rim damage
18	F	67	Biolox forte/Biolox forte	28	143	10	Noise due to fracture of the head
19	F	68	Biolox forte/Biolox forte	28	37	15	Noise due to rim damage
20	M	38	Biolox forte/Biolox forte	36	52	8	Noise due to rim damage
21	M	53	Biolox forte/Biolox forte	40	44	10	Pain and noise due to cup loosening and rim damage