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Original Research Article

The surface topography of a metallic femoral head and its influence on the wear mechanism of a polymeric acetabulum

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ABSTRACT

The wear mechanisms of friction components depend on conditions of articulation, material properties and surface topography of the co-acting parts. Therefore, it is important to examine these determinants in order to improve the durability of a friction pair. With the view of securing the longer life of articulating surfaces, a metallic femoral head used in conjunction with a polymeric acetabulum was subject to research. The components of the friction pair were prepared in accordance with the standard specification ASTM F2033-12. From the precision machining process of metallic femoral heads, two different kinds of surface topography (defined by Ra parameter: $Ra(A) < Ra(B)$) were obtained. The tribological research was performed with a testing machine simulating the kinematic movements and the working conditions of a natural joint (friction pair: ball-and-socket) in the Ringer's solution. The measurements of the surface topography (machined and worn surfaces) were conducted using the following measuring devices: coordinate measuring machine, white light interference microscopy and scanning electron microscopy. Based on the analysis results, the influence of the surface topography of the metallic ball upon tribological characteristics was determined. The wear mechanisms of the polymeric socket resulted from a number of phenomena, including plastic deformation, abrasive wear, fatigue and adhesion.

1. Introduction

In the human osteoarticular system, the important role is played by synovial joints, among them the hip joint. Due to heavy loads that it carries during movement, it is exposed to destruction, deformation, mechanical damage and pathological changes [1,2]. When the hip joint loses its primary functions, at first pharmacological and relieving treatments are applied. If these methods are of no avail, surgical treatment becomes a necessity. Arthroplasty counts amongst most common hip joint reconstruction surgeries. It is based on

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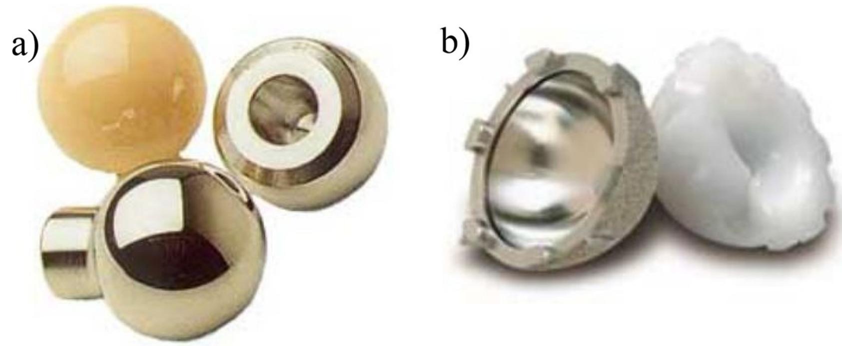

Fig. 1 – Hip joint prosthesis components [7]: (a) femoral heads and (b) acetabulum.

replacement of a natural hip joint with an artificial equivalent called endoprosthesis, which helps restore the lost motor function to the joint. The durability of the prosthesis ranges from 7 to 12 years, depending on the way it is exploited [3–6]. Due to relatively short use of prosthesis and the necessity for replacing it, solutions that would ensure its longest possible operation are looked for.

It is important to constantly seek for better materials and construction solutions with regard to prosthesis components (Fig. 1), which in turn requires a lot of research to be carried out, not only from the biomedical but also technological point of view.

Technological research encompasses, among others, measurement and analysis of the surface topography obtained during the manufacturing process (machined surface MS) and the surface topography obtained from tribological test (worn surface WS), i.e. shape, waviness, roughness and surface defects [8–11]. On the basis of the results obtained from technological research, it is possible to evaluate the accuracy of dimensions and shape, the quality of the machined surface [4,12–16] and the influence they have on the functioning [17,18] of the ball-and-socket prosthesis.

The dimensions (tolerances), the shape, the surface quality of hip replacement parts (femoral head and acetabulum) as well as the method of their measurement are specified in ASTM F2033-12 2012 *Standard Specification for Total Hip Prosthesis and Hip Endoprosthesis Bearing Surfaces Made of Metallic, Ceramic and Polymeric Materials*.

Sphericity (radial deviation of roundness Δ – circularity) of artificial femoral heads should be designated in planes marked with AA, BB, CC, which is indicated in Fig. 2a; the acetabulum – according to Fig. 2b. The requirements relating to the surface roughness (defined by *Ra* parameter – arithmetic mean deviation of the roughness profile) should be checked by performing measurements in the planes marked with AA (a), BB ($b = 2a/3$), CC ($c = a/3$) and pole P, which is indicated in Fig. 2a and b.

According to the standard ASTM F2033-12, firstly, when using 5-diopter magnification, the bearing surfaces should be free from particles and scratches other than those arising from the machining process (finishing process). Secondly, the bearing surfaces of metallic femoral heads of total hip joint prostheses used in conjunction with a polymeric acetabulum should have a *Ra* value of not greater than 0.05 μm, while the departure from roundness Δ shall not exceed 10 μm.

The spherical bearing surface of the acetabulum shall have a *Ra* value not greater than 2 μm and the bearing surface of the polymeric acetabulum shall be free from particles, scratches, and score marks other than those arising from the finishing process.

The standards generally provide the value of *Ra* parameter as a guideline for preparation of objects in the manufacturing process. It should be noted that the *Ra* parameter is only an average arithmetic deviation of the roughness profile, and therefore it does not reflect the surface characteristics thoroughly. Hence, in the standards (ASTM F2033-12) it is recommended that other profile parameters, more sensitive to local peaks or valleys, should be taken into consideration while analyzing surface texture. It is commonly known that the assessment of the surface topography based exclusively on 2D

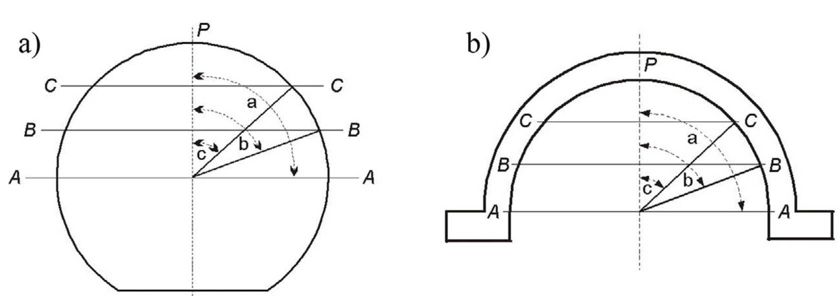

Fig. 2 – Locations of measurement points of total hip joint prosthesis (ASTM F2033-12): (a) for femoral head and (b) for acetabulum.