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Types of wear and tear of biomaterials used in orthopaedic surgery

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ABSTRACT

Purpose: Purpose of this paper is presentation of observations on different kinds of wear and tear of biomaterials used in contemporary orthopaedic surgery.
Design/methodology/approach: Types of prosthesis damage, encountered in medical practice, and their causes have been described. Results of many clinical studies were analysed to review prosthesis damage from the stage of implanting (such as intrusion of a foreign object between its components) to their natural wear and tear after many years of use (abrasive wear, biological corrosion).
Findings: It has been shown that prostheses heads may also succumb to quick wear and tear despite being made of harder and more durable materials than sockets.
Research limitations/implications: Clinical and laboratory of defective implants discover the reasons of damage, but they are time consuming. There are also difficulties in obtaining objects for research.
Originality/value: The research has helped to systematise the knowledge on the mechanisms of wear and damage of endoprostheses, which is vital for improvement of their life cycle.
Keywords: Fracture mechanics; Fatigue; Wear mechanism; Hip replacement prosthesis; Knee replacement

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1. Introduction

Present capabilities of medicine in orthopaedic surgery allow millions of patients with joint problems to live normal lives [1]. The most frequently implanted are the hip and knee joint prostheses. Dysfunctions of those organs considerably affect a person's health condition and mobility. Those joints are most frequently deformed or damaged mechanically [2,3]. Currently, hip, knee and shoulder joint prostheses have become generally available and the issues related to their production and use have become the object of thorough research [4-9].

The most common problems encountered when using joint prostheses include abrasive wear of their components and loosening of implants. Both those factors significantly contribute do implant damage, but premature abrasive wear of their parts may be caused by other reasons, such as [2,10-18]: improperly selected friction pair, incorrect position of the prosthesis parts

(incorrect pressure distribution in the contact zone), degradation of the polymer material caused by radiation sterilisation, overloading of the friction pair, damaging of the surface layer of the contacting prosthesis parts or roughness of the surface of the head of a bone.

There have been many literature reports of research describing the tribological processes that take place in individual prostheses [18]. Results of such research usually include values of linear and mass wear, less frequently values of frictional resistance. This paper provides a review of the issue and focuses on the types of damage to implant surface, observed during clinical studies of used hip joint implants (in particular examination of wear and tear, material degradation or the condition of an implant surface after it was used by a patient).

A hip joint was one of the first objects of interest of orthopaedic surgery. It is a spherical joint formed by the head of the femoral bone and the hip joint socket of the pelvis. It transfers the body weight from the trunk to the lower limbs and enables their movement. Heads of hip joint prostheses are usually made of hard materials, such as metal alloys or ceramic materials, whereas sockets are usually made of polymers.

Results of clinical studies and laboratory analyses described in the literature [2] enable one to identify typical types of damage to the parts made of polymers: abrasive wear, which manifests itself in changed micro- and macrogeometry of the surface, plastic deformations (caused by exceeded maximum acceptable load of knee joint implants), creep, fatigue wear (pitting), material degradation (change of its structure and chemical composition), loosening and cracking.

The type of material association is the fundamental factor which affects the process of wear of friction elements [19-28]. P. Kowalewski reports [17] that research is being conducted aimed at identification of the effect of individual kinematic factors, such as unit pressure [29-33] and slide speed [24,30,32,34], on the intensity of wear of friction parts. The condition of the surface layer of a polymer and metal element is also important [22,30].

The most frequently described problems which cause later complications include loosening of prosthesis elements in a bone or infections. They usually result in the prosthesis removal, and its reimplantation is not always possible. However, those are not the only problems.

2. Clinical studies of prostheses material wear

One of the tribological pairs in a hip joint prosthesis is the „prosthesis head - socket" moving contact. The process of wear in the contact depends mainly on the type of friction pair and the surface roughness. Of the two elements (socket and head) which are in contact in an implant, the socket is more susceptible to wear as it is made of a softer material (they are made of plastic - usually hard polyethylene (HDPE or UHDPE), while heads are made of metal or ceramic materials). Examples of images of sockets - both new and damaged as a result of different types of wear - are shown in Figs. 1-5, with Fig. 1 being the reference image for all the studies described in this paper.

As the photographs show, the nature of wear of an implant sockets is highly varied. Compared to new sockets, whose surface is very smooth (Figs. 1 a, b), the surface of used sockets is in much worse condition. The most common type of wear observed in the sockets under examination was damage caused by biological corrosion (Figs. 2 a, b). This indicates insufficient resistance to that type of corrosion of the materials used for the implants. Despite using hard PE to make prostheses sockets, sometimes the material is seen to flow (Figs. 3 a, b).

Some socket surface has been seen to crack (Fig. 5a). However, abrasive wear has been the most common type of damage to their surface (Figs. 4 a, b). This may have been caused by elements of the socket material which have chipped off during the joint use (Fig. 4) or foreign bodies (Fig. 5 b) which entered the "prosthesis socket - head" contact zone. This has been confirmed by authors of other publications [2,35], whose studies have shown that parts of prostheses made of hard metals, which are in contact with polyethylene, do not show signs of significant wear even after more than ten years of use. Only hard products of wear, e.g. chips of bone cement, which enter the friction zone, can scratch the smooth surface of the metal element.

a) b)

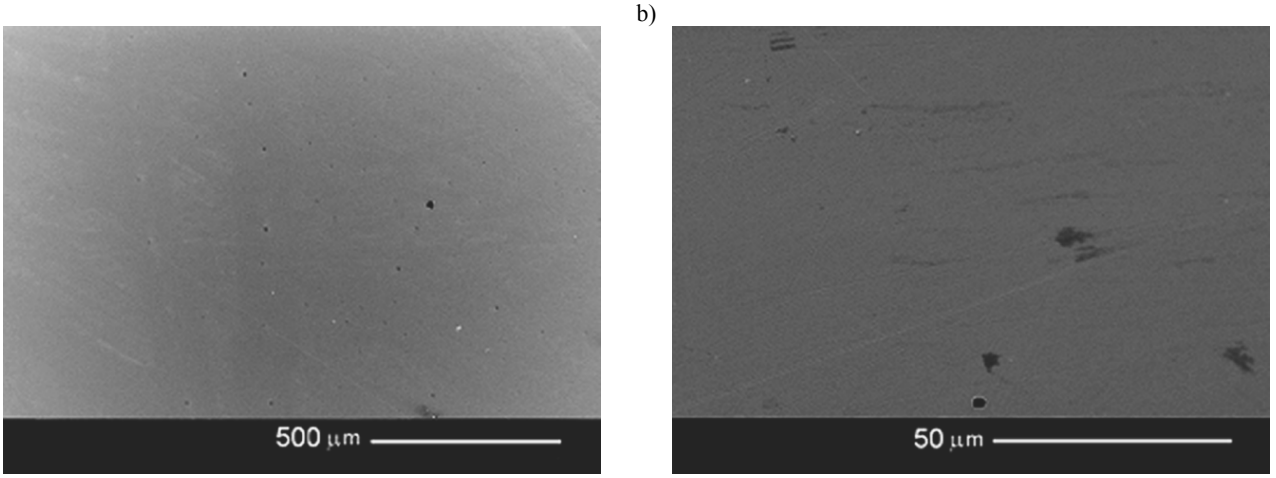

Fig. 1. The surface of a new socket - images at different magnifications

a) b)

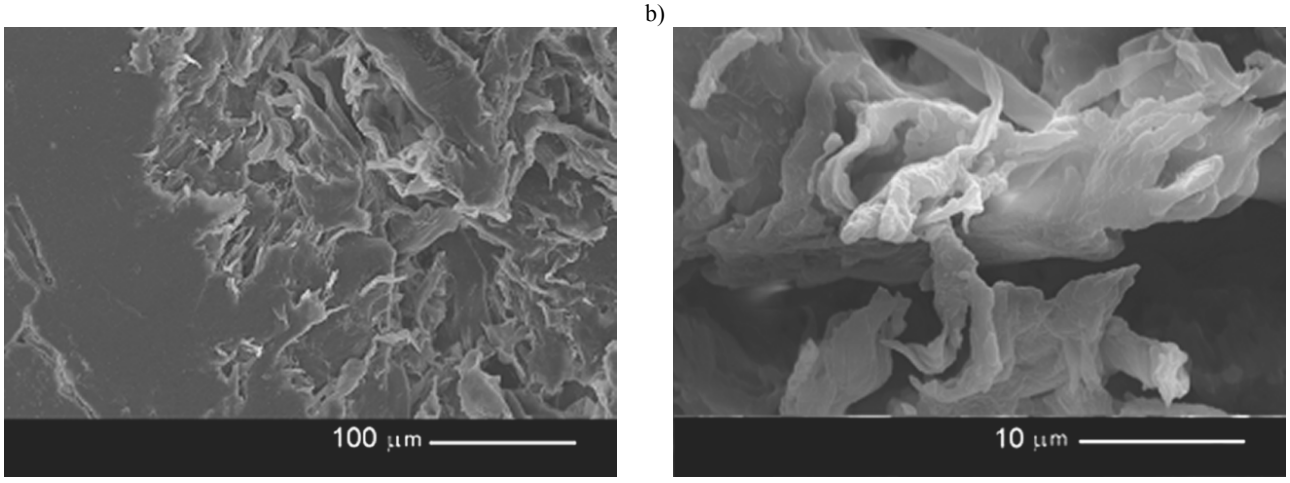

Fig. 2. The surface of a socket damaged as a result of biological corrosion

a) b)

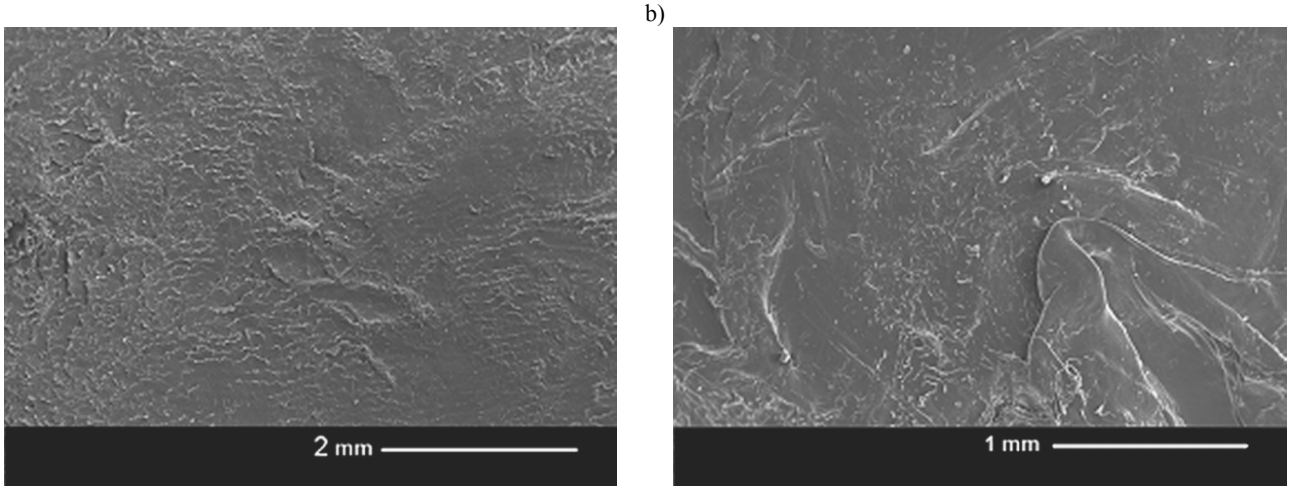

Fig. 3. Plastic flow of the socket material

a) b)

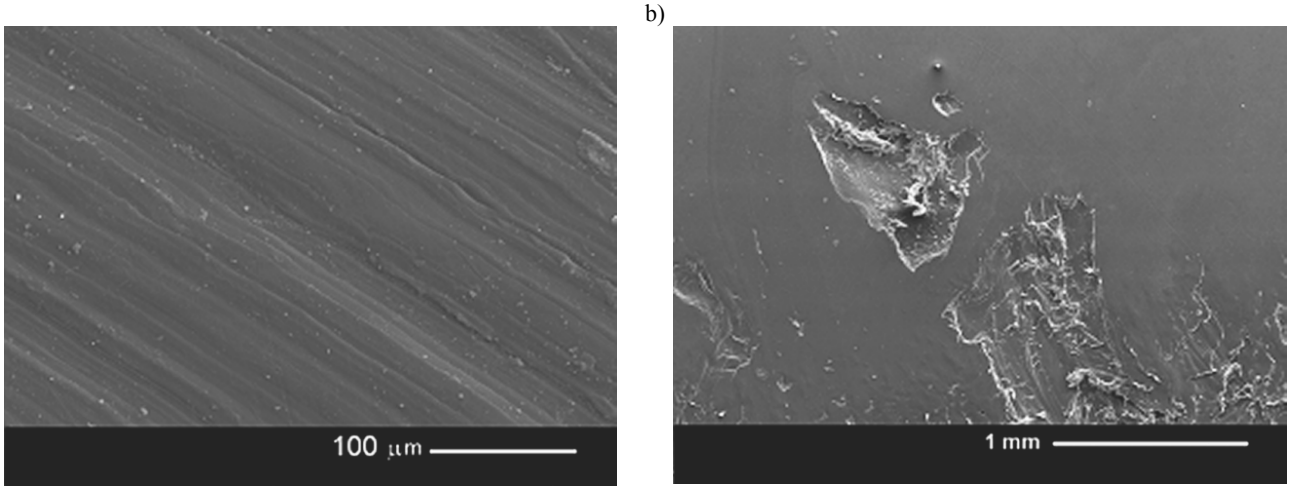

Fig. 4. Examples of different types of wear of hip joint prostheses sockets: a) abrasive wear, b) chipping the sockets material

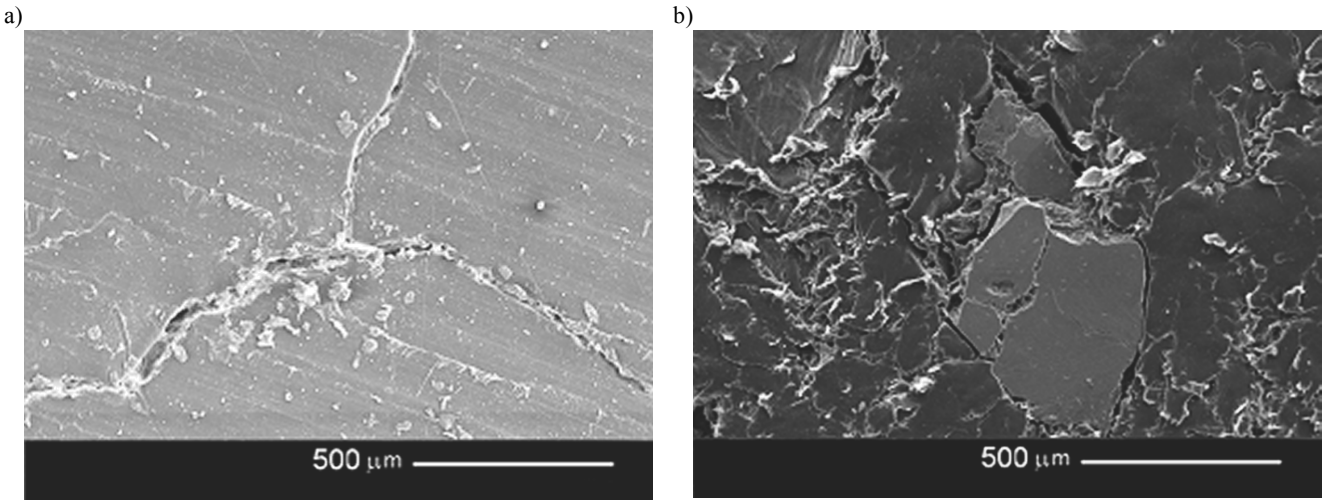

Fig. 5. Examples of different types of wear of hip joint prosthesis sockets (continued): a) socket cracking, b) denting by foreign material

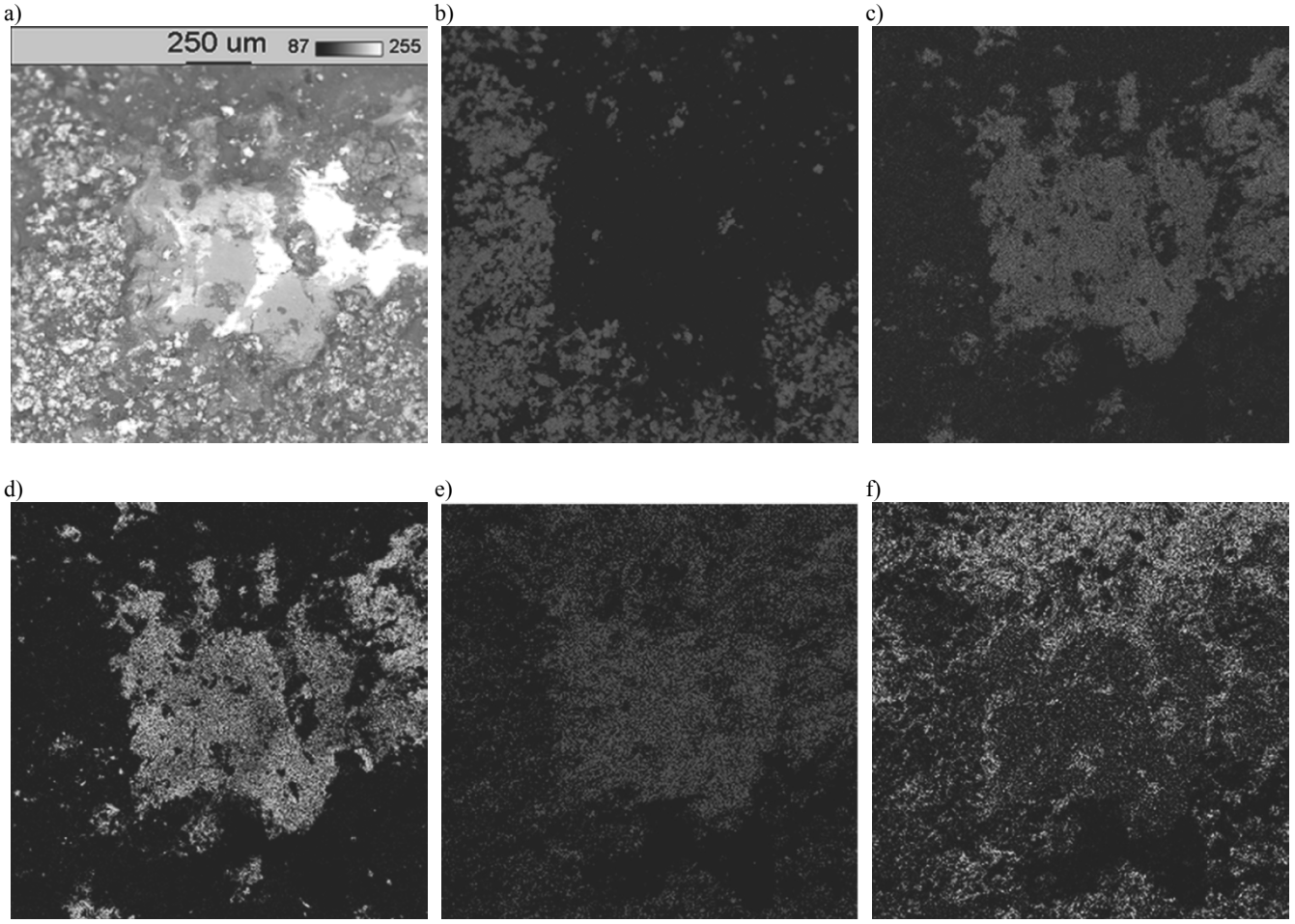

Fig. 6. Intrusions in titanium socket: a) image of the intrusion, b), c), d), e), f) distributions of titanium, phosphorus, calcium, oxygen and carbon

Some elements have been observed on the sockets surface which may have come from the patient's body. As is seen on the maps of surface element distribution, the intrusion shown in Fig. 6 contains mainly calcium, phosphorus and oxygen. Those elements are found in hydroxyapatites, which are the main components of bones. This allows one to conclude that the element entered between the head and the socket during the prosthesis implanting procedure.

Despite being made of harder materials (metal alloys, ceramic materials), heads of hip joint wear out more quickly than sockets. Intrusions of foreign material are also observed on their surface, as shown in Fig. 7 and Fig. 8. Due to stochastic aspects related to formation, migration and characteristics of those hard foreign bodies, it is difficult to anticipate the disadvantageous positions of the head, as is the moment at which a disadvantageous change in roughness occurs. Therefore, it needs to be stated clearly that the knowledge of the mechanism of scratching the head of the femoral bone is not complete.

An analysis of the chemical composition has shown that certain titanium elements appeared on the prosthesis head, made of Co-Cr-Mo alloy (Vitalium). As the map of titanium distribution (Fig. 9) shows, its presence exactly coincides with the eruption. Titanium is not as hard as the Vitalium alloy, so those are not particles stuck into the surface; rather they are spread on the surface. Therefore, its presence here has different reasons. As the socket casing was made of titanium, the eruption on the surface may originate from it. This indicates that apart from typical wear processes by friction, a process of dissolving titanium by body fluids and transporting it to other places takes place.

Apart from intrusions, there are also other types of wear observed on the surface of a prosthesis head. The surface of a non-worn head, shown in Fig. 10, is relatively smooth and there are only scratches on it caused by mechanical processing. A worn prosthesis head looks completely different (Fig. 10b). This is typical wear observed in cutting elements. Material defects and traces of its plastic flow are visible.

a) b)

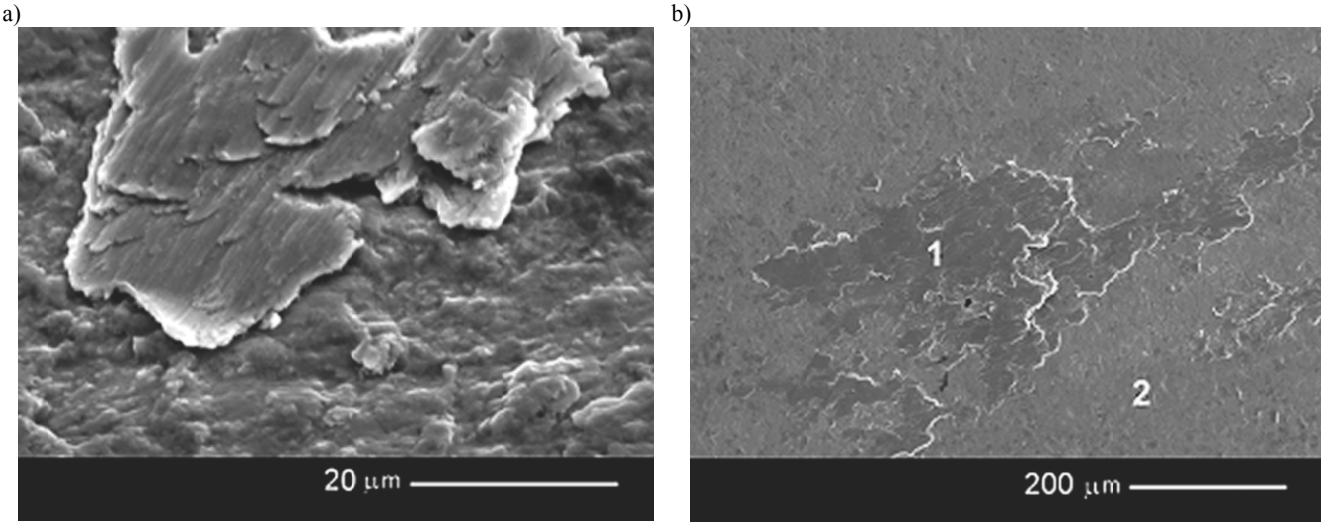

Fig. 7. Foreign material on the surface of hip joint prostheses heads a, b) different size of intrusions

a) b)

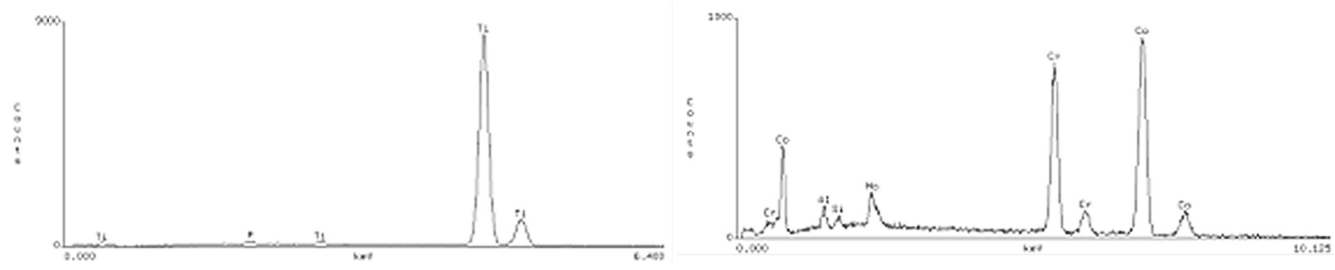

Fig. 8. Foreign material on the surface of hip joint prostheses heads from Fig. 7: a) EDS spectrogram from point 1, b) EDS spectrogram from point 2

a) b)

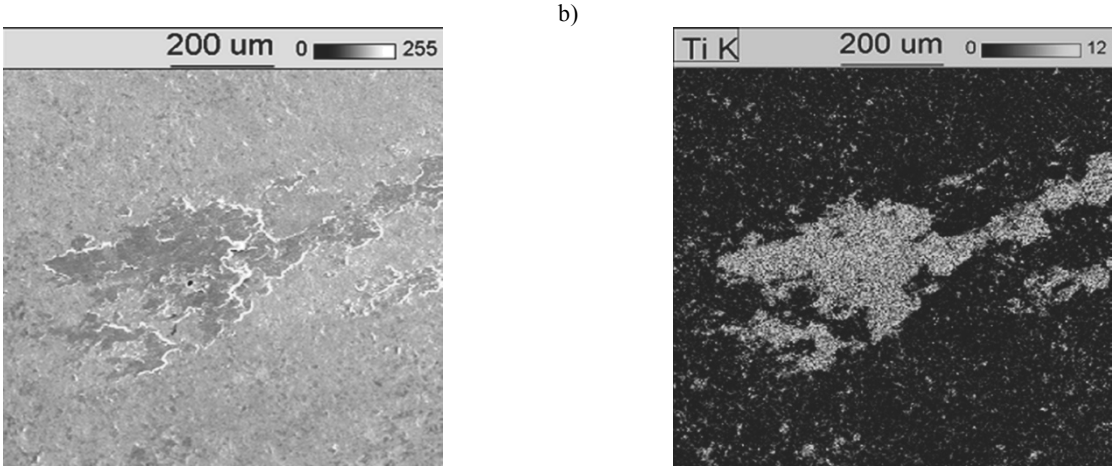

Fig. 9. Foreign material on the surface of the head of a hip joint prosthesis: a) image of the intrusion,b) surface distribution of titanium.

a) b)

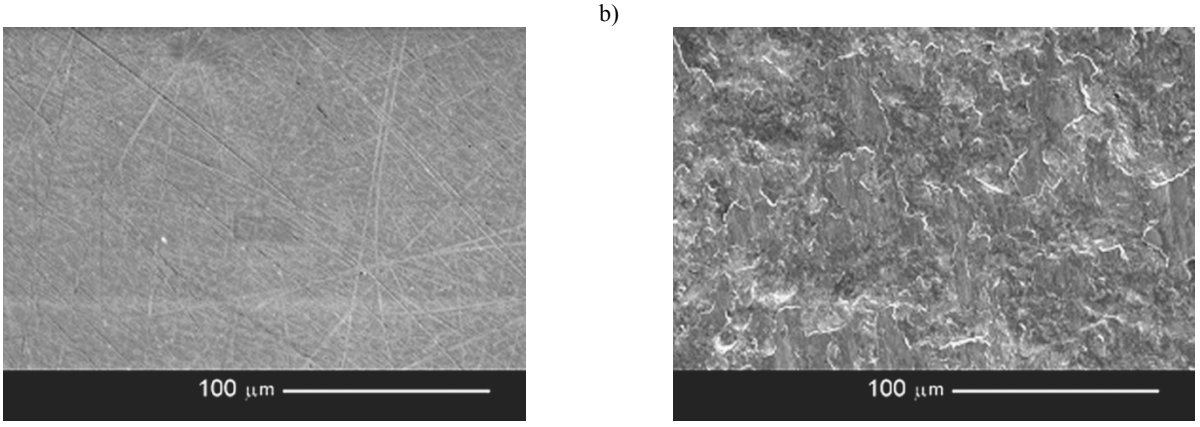

Fig. 10. Examples of different types of wear of heads of hip joint prostheses: a) non-worn surface, b) surface worn by friction

3. Conclusions

Due to an unusual nature of movements as well as the type of contact and material used, prostheses may be regarded as non-conventional friction pairs; hence the most common causes of damage of those elements are related to friction. However, those are not the only reasons.

Based on results of clinical and laboratory studies, the authors have analysed and described the most common types of damage of components of heads and sockets of hip joint prostheses: abrasive wear, plastic deformations, fatigue wear (pitting), degradation of material (change of its structure and chemical composition), chipping and intrusions, biological corrosion and cracking. It has been shown that prostheses heads may also succumb to quick wear and tear despite being made of harder and more durable materials than sockets.

The knowledge of the mechanisms of wear and tear and damage to joint prostheses is extremely important for efforts aimed at extending their life cycle and improving patients' comfort. It must be borne in mind that the prosthesis implanting procedure is often the only chance for patients to regain the ability to move and to live a normal life when their natural joints have failed.

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