FAILURE ANALYSES OF A NON-CEMENTED HIP PROSTHESES FAILED DUE TO THE STEM FRACTURE

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The paper presents the fractographic analysis of a ceramic-ceramic hip prosthesis that failed prematurely due to the fracture of the metal stem of the prosthesis. The investigation methods used were stereomicroscopy, optical microscopy, scanning electron microscopy and EDS spectrometry. Analyzes have shown that the metallic biomaterial (TI6Al4V) is suitable in terms of chemical composition and microstructural characteristics, no material defects have been identified. The analysis of the failure zones highlights a fatigue type fracture, followed by a friction-wear phenomena between the fractured components of the hip stem. The final failure of the prosthesis occurred with a shock.

1. Introduction

Arthroplasty is a common procedure that restores the integrity and function of a joint. This procedure can be done by replacing degraded surfaces or by completely replacing the hip joint [1, 2]. The arthroplasty procedure is performed when the joint disease reaches a worrying level of evolution and can no longer be stopped by non-invasive orthopedic treatments (physiotherapy), by minimally invasive treatments or surgical treatments [3].

Endoprosthetic arthroplasty is the most used type of arthroplasty and involves replacing the joint with a joint prosthesis called an endoprosthesis [4]. Is

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used on large joints (hip, knee, shoulder), middle joints (elbow, ankle) and small joints (the joint of the fingers / toes) [5].

Biomaterials are used now successfully used not just in arthroplasty, but also in many medical specializations like dentistry [6,7], neurosurgery [8,9], ophthalmology [10], gynecology [11, 12], cardiovascular surgery [13, 14], and general surgery [15, 16, 17].

As components, the hip prosthesis consists of the femoral stem, the femoral ball and the acetabular cup [18,19] and, in some cases, depending on the friction torque, a polyethylene insert is used [20,21].

Implants used for arthroplasty are manufactured using iron-based alloys such as stainless-steel 316L, titanium-based alloys, cobalt-chrome-based alloys for stem and, ceramics like alumina or zirconia are used for the acetabular cup the polymetilmetacrilate being used for the liner.

The components can be fixed using a bone cement [22] (for the cemented prosthesis) or by a porous sintered layer deposited on the cup and stem of the prosthesis that allows bone growth (uncemented prosthesis) [23, 24]. Cemented prostheses are used in patients over 65 years of age because they provide good initial strength, but there is a risk of further weakening over time [25].

Fig.1. Hip prosthesis components

Uncemented prostheses are used in young patients, but they need a 6-week implant protection [26] and, in the long run, ensure a good fixation.

The parameters [27] that influence the biofunctionality of a stem [28] must be considered, such as mechanical stress, corrosion related to the bone-implant system, but also to the patient, the type of implant and the doctor (chosen surgical technique and implant positioning). If these parameters are not considered, the endoprosthesis can lead to failure [29].

The hip joint is a synovial joint [30, 31] that attaches the lower limb to the human torso and allows for a wide range of movements. The hip joint can support the full weight of the body, while providing stability, as it happens while walking. The purpose of the replacement is to reduce pain [32] and restore function by separating the exposed bone and creating a low-wear friction torque. Fixations techniques and the type of bearing surfaces are the two main concerns in the design of such prostheses [33].

The aim of the paper was the fractographic evaluation of a prematurely failed metal-ceramic hip stem. The prosthesis was taken from a 62-year-old patient who underwent total unilateral hip arthroplasty 4 years ago and we mentioned that the prosthesis was not cemented.

2. Materials and methods

The analyzed material is taken from a failed total hip stem, the fracture being directly perpendicular to the application of loads.

Two experimental samples taken from the broken prosthesis were metallographically prepared, in cross section and in longitudinal section, in order to be analyzed by optical microscopy. The surface of the samples was grinded with sandpaper of different grainsize (from 180 to 1200 grit size), followed by polishing using diamond paste (9, 3 and 1 μm and final polishing at 0.05 microns). The microstructure of the samples was studied both on unetched and after the metallographic etching. The microstructure before the metallographic etching is useful when it comes to inclusions analysis, which is very important in fractographic analysis.

Macroscopic imaging was made on an OLYMPUS SZX stereomicroscope to provide a detailed investigation of the fracture surface. The optical microscopy analysis was made on a Nikon Inverted Microscope using normal illumination. The breaking surface was studied using a scanning electron microscope (SEM), coupled with an energy dispersive X-ray spectroscopy (EDS) model Philips ESEM XL 30 TMP.

2.1. Clinical Details and Circumstances of Implant Failure

The patient was a 62-year-old male, weighing 101 kg and measuring 172 cm in height, with a BMI (body mass index) of 34.1 kg/m^2 at the time of stem revision. From previous medical documents and discussions with the patient we found that at the time of the primary cementless unilateral (left side) THA (Total Hip Arthroplasty) (early 2017) the patient weighed 105 kg, with BMI of 35.5 kg/m^2, followed a non-weight bearing walking protocol for 5 weeks after surgery and gained a total of 6 kg in the next 2 months following the primary THA surgery, bringing him to weighing a total of 111 kg , with a BMI of 37.5 kg/m^2.

The patient was a smoker with a known pathological history, suffering from type II diabetes, diagnosed in 2010. The daily level of physical activity of the patient prior to total primary hip arthroplasty was moderately active (8 hours per day) which consisted of walking and driving.

During late 2020 the patient remembers feeling a sudden onset pain in the upper left thigh and unsteadiness while getting out of the car after a 40 minutes' drive (60 km). The patient denies any kind of pain or unsteadiness after his rehabilitation period and before the upper related incident and he does not dispose of other X-rays beside his first post-op checkup X-ray (Figure 2a). After the incident he continued walking with a crutch and went for a checkup at approximately 2 weeks after the incident (Figure 2b).

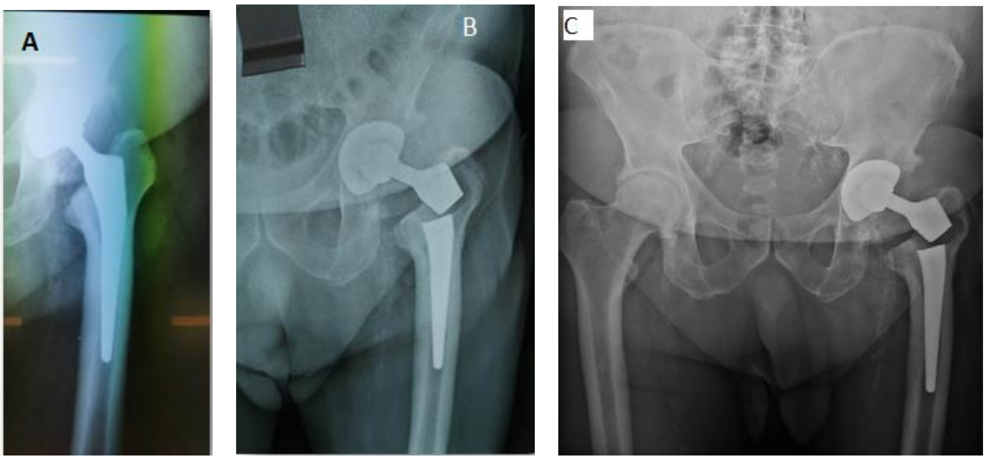


Fig.2. Radiological aspects of the investigated clinical case: (a) Total hip arthroplasty with uncemented stem 6 weeks after surgery; (b, c) appearance of the stem failed 4 years after primary implantation.

3. Results and discussion

3.1. Fracture Surface Investigation by Stereomicroscopy

The overall picture of the total hip prosthesis is shown in Figure 3. It is observed that the rupture is in the area of the intramedullary component, in the first third of the total length of the stem. The rupture is in a direction perpendicular to the application of the loading.

Fig. 3. General view of failed HIP prosthesis

The stereomicroscopy analysis revealed both the propagation of the fracture and the different macrostructural aspects specific to the fracture of the investigated stem.

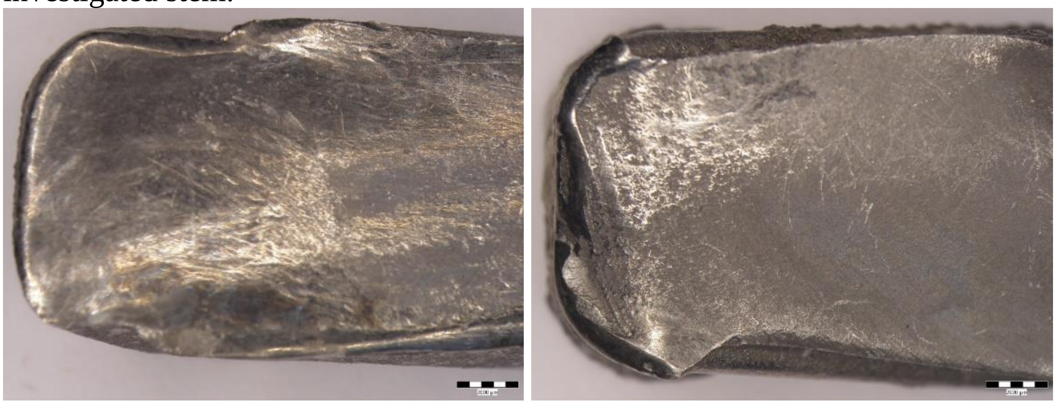


Fig.4. Macrostructural appearance of different marginal areas of the intramedullary stem of the explanted hip prosthesis

Macrostructural aspects of the stem ends, highlighting the propagation of the rupture, with beachmarks, but also with the visualization of the area of initiation of the fracture, a discontinuity of material.

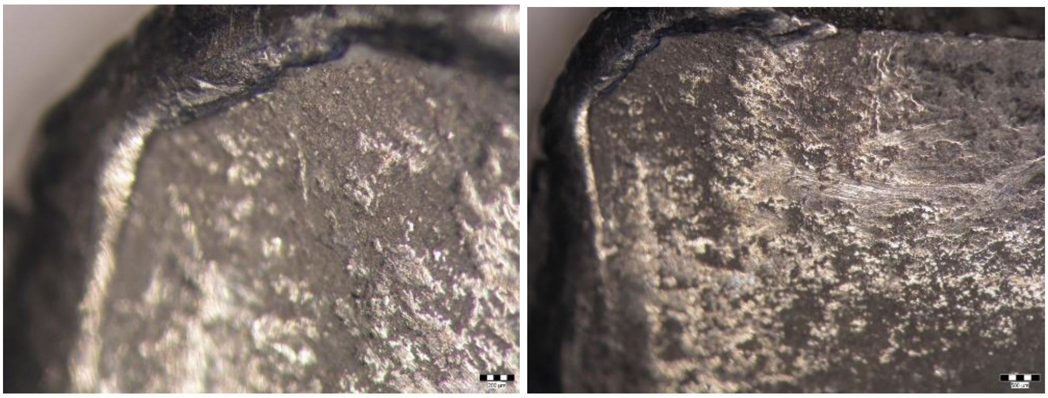
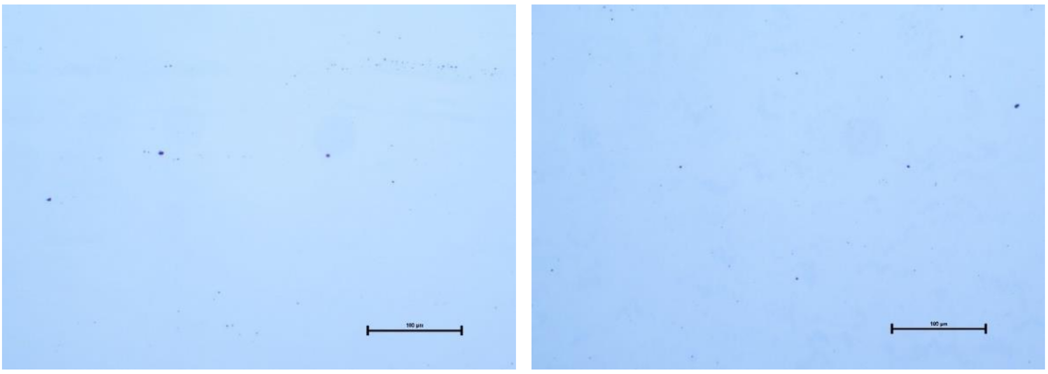


Fig.5. Stereomicroscopic images showing details of rupture in different areas of the intramedullary stem of the explanted hip prosthesis

3.2. Optical microscopy investigations

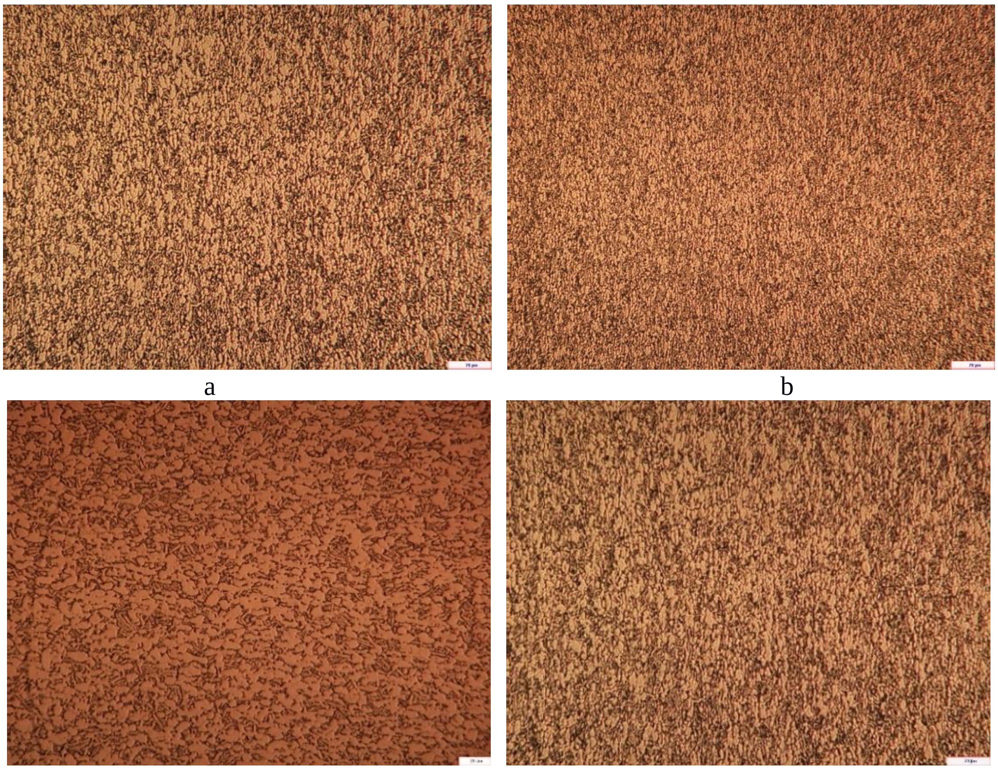
Images on the longitudinal and transversal sections (Figure 6) of the unetched samples shows an alloy without significant inclusions.

Optical microscopy determinations for the experimental sample taken from the hip prosthesis in cross section (Figure 7 a and b) showed a structure typical of the Ti6Al4V alloy. Considering the magnification at which the image was taken, it can be stated that the structure is uniform and fine. Optical microscopy determinations for the experimental sample taken from the hip prosthesis in the longitudinal section (Figure 7 c and d) showed a biphasic structure (α + β) typical of the Ti6Al4V alloy.



a b

Fig. 6. Optical microscopy images - unetched samples a) longitudinal section, b) cross section



a b

c d

Fig. 7. Optical microscopy images - microstructure experimental sample taken from the hip prosthesis: a, b) cross section; c, d) longitudinal section

3.3. Fracture Surface Investigation Using SEM

The surface of the experimental samples was analyzed in detail using scanning electron microscopy (SEM). The imaging results obtained for each type of experimental sample are shown in the following images (Fig. 8) :

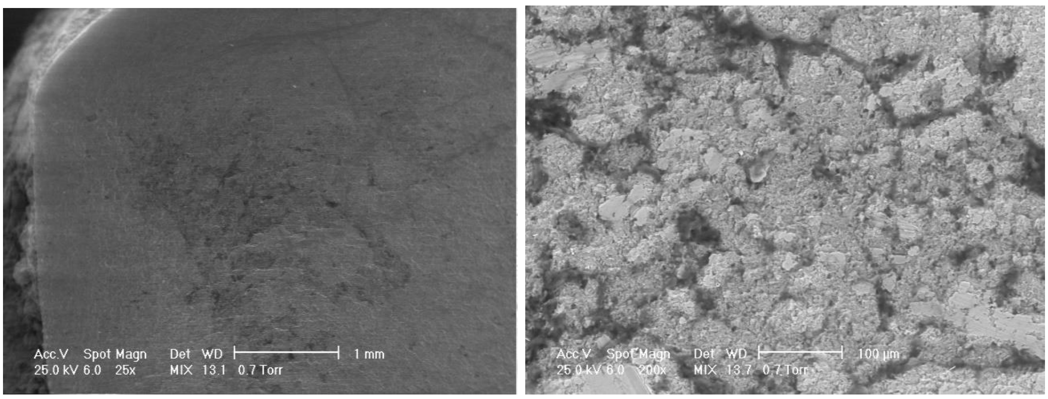


Fig.8. a) SEM images of the fractured femoral component surface of the investigated total hip prosthesis (marginal area analysis, at different magnification)

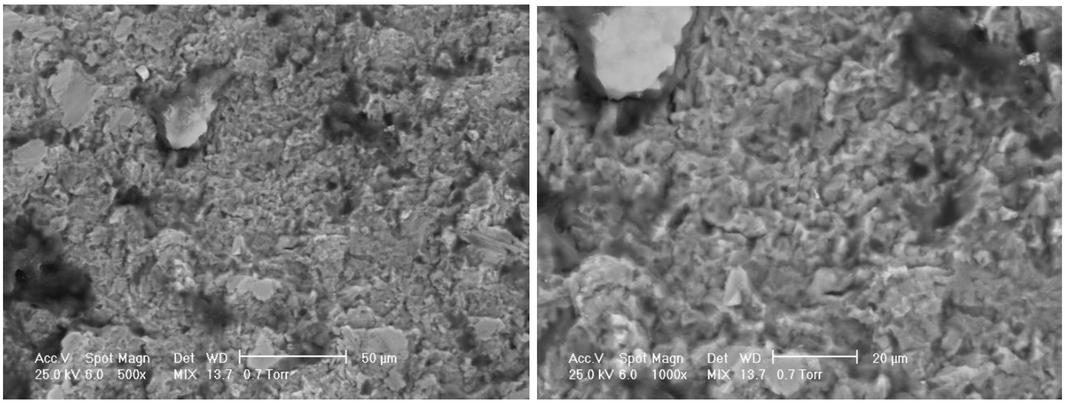


Fig.8. b) SEM images of the fractured femoral component surface of the investigated total hip prosthesis (marginal area analysis, at different magnification)

The SEM images recorded on the samples show the morphology of each type of experimental sample taken from the investigated hip prosthesis. The margin area of the fractured area of the femoral component of the total hip prosthesis investigated reveals a matte, fibrous appearance.

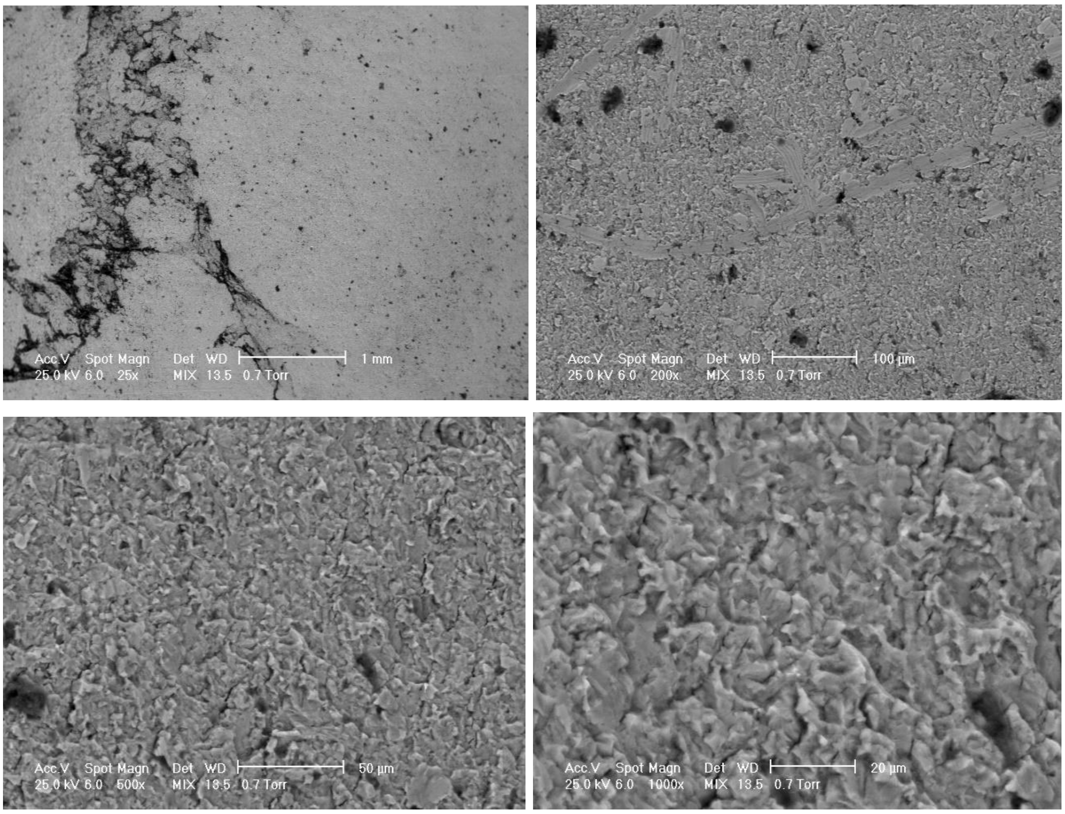


Fig.9. SEM images of the fracture area of the investigated total hip prosthesis femoral component of the (plateau area analysis, at different magnification powers)

At high magnification, the character of the rupture is highlighted, with gaps finely distributed in the analyzed field.

The central area of the fracture area of the femoral component of the total hip prosthesis investigated with a rough appearance. The area with propagation waves of the rupture, at high magnification, shows the fatigue fracture character.

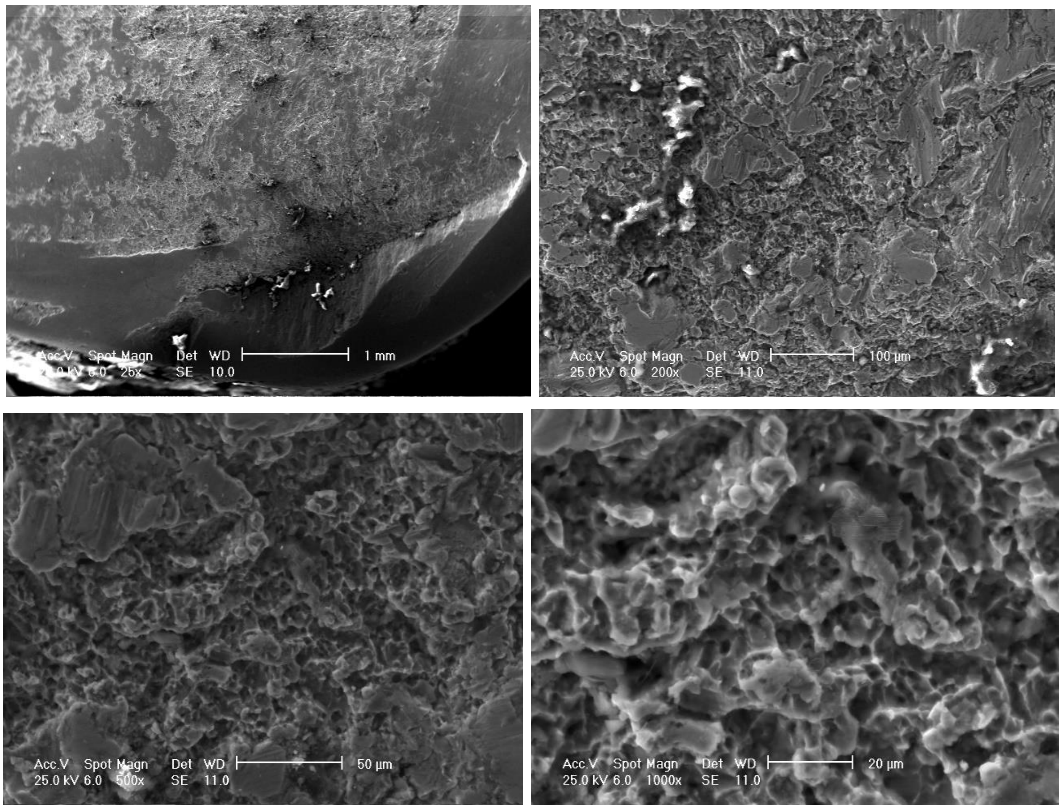
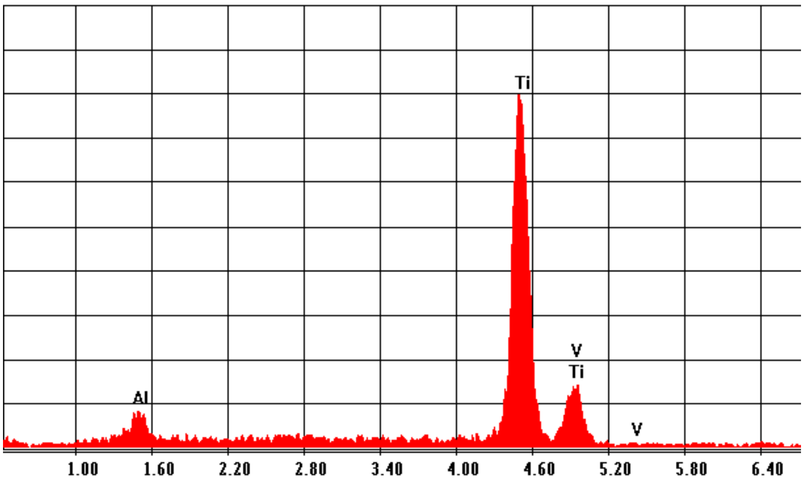


Fig. 10. SEM images of the rupture surface of the fracture area of the investigated total hip prosthesis femoral component



Element	Chemical composition [wt%]
Ti	89.94
Al	6.08
V	3.98

Fig.11. SEM-EDS analysis results

The edge of the fracture area of the investigated femoral component of the total hip prosthesis, probable highlighting the place of initiation of the fracture, probably a discontinuity of material. The fracture has a fatigue character, the chamfered ends, showing a relatively long friction between the moment of rupture of the investigated femoral component of the total hip prosthesis and the moment of revision. At high magnification, this fracture character is clearly visible, with numerous gaps, but also small plateaus. The results of the EDX analysis indicate that the material from which the femoral component of the total hip prosthesis investigated is made is a titanium alloy, respectively Ti6Al4V.

4. Conclusions and future research directions

Failure of the hip stem due to fracture of the femoral stem is a rare phenomenon in modern orthopedic surgery. This occurrence is caused by material defects that can act as crack initiators or, in rare cases some biomechanical shock overloads of the prosthetic assembly.

Regarding the failure of the investigated hip stem, it was demonstrated that the metallic biomaterial used, namely TI6Al4V, is appropriate in terms of chemical composition and microstructural characteristics, no major material defects being identified. Analysis of the surface of the fractured femoral component shows a fatigue fracture, the chamfered ends presenting also a sign of a relative friction between the time of rupture of the femoral component and the time of revision. Due to his rigid position, he did not notice the pain until he got out of the car. After the fracture of the femoral component and before the revision surgery, there were inherent friction-wear phenomena between the fractured components of the tail of the femoral stem.We can conclude that the failure of the prosthesis was due to fatigue, the final failure occurred by a sudden overload while driving.

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