Investigation of premature failure of hip joint replacement

P Hanusová, P Palček, M Roszak, V Zatkalíková

University of Žilina, Faculty of Mechanical Engineering, Univerzitná 8215/1, 010 26 Žilina, Slovakia

E-mail: patricia.hanusova@fstroj.uniza.sk

Abstract. Hip joint replacement is one of the most frequently used surgical procedures worldwide. Currently, more than 340 of the total 4431 implants per year are reoperated in Slovakia. Despite the excellent properties of the titanium alloy, endoprosthesis often fails and hip replacement is necessary. Common causes are inflammation and aseptic loosening. Other causes of failure include injury, implantation failure, manufacturing inaccuracies, and aseptic loosening. The case study of a failed endoprosthesis is carried out in cooperation with the Orthopaedic Clinic of the University Hospital in Martin, Slovakia. The patient necessarily needed THA and this paper deals with the causes of failure of his total hip joint replacement.

1 Introduction

Titanium alloys are considered the most attractive metallic materials for biomedical applications because of their biocompatibility, high corrosion resistance, and appropriate mechanical properties [1]. Biomaterials are materials intended for direct contact with the internal tissues of the human body. Both the recipient and the implanted material must be carefully studied, as foreign substances are placed in the chemically active environment of the body. Biomaterials are classified into four categories according to the interaction with the recipient. An inert material that elicits a favorable reaction, such as growth. A viable biomaterial that includes living cells at implantation that the host perceives as normal and that is actively absorbed. The implant material is the original material that is cultured in vitro from cells obtained from a patient and subsequently implanted. And a biomaterial that serves as a replacement for part of the human tissue in the support system [2].

![Number of operations in Slovakia](image-url)

**Figure 1.** Number of operations in Slovakia since 2003
At present, Ti-based alloys consist of biocompatible alloy bases that replace both hard tissues and dental ligaments. Ti-based alloys are also used to repair soft tissue, such as blood vessels [3]. During biomedical applications, various ways of compressive, tensile, and shear stresses may occur in the material. Sometimes there is a combination of all three. In a typical tensile mode, the same force is applied perpendicular to the surface of both ends of the sample in opposite directions, while during compression the force is applied perpendicular to both ends in the opposite direction. In shear loads, the forces acting tangentially on opposite surfaces. Due to differences in properties, biomaterials are divided into four groups: metals, ceramics, and polymers, and composites [4]. The generation of polyethylene wear debris is a major cause of aseptic loosening, and the most common reason for THA revisions. The interaction of particles and cells in periprosthetic tissue and surrounding bone contributes to the deregulation of bone homeostasis resulting in osteolysis at the bone–implant interface [5].

In 2018, 458 patients underwent revision surgery (Figure 1), of which 60 at Martin Hospital. In collaboration with physicians from the Orthopedic Clinic of the University Hospital in Martin, where the patient underwent the necessary reoperation, we analyzed the possible causes of failure of the titanium endoprosthesis (Figure 2), to prevent other possible complications [6]. A 61-year-old patient underwent a left hip replacement in 2008 at the Orthopaedic Clinic of the University Hospital in Martin. After two years, he underwent surgery to replace his right hip joint. The man's BMI at that time was 27.8, so his height was 180 cm and his weight was 90 kg. In 2018, the patient began to feel pain in his left hip, could not walk, and had a fever of 38.1 °C. The indicator of the inflammatory response of CRP reached the value of 170.5 mg l-1, the physiological value of which is up to 10 mg l-1.

2 Materials and methods

The chemical composition of the failed endoprosthesis was examined using a SPEKTROMAXx device (Table 1). The spectral analysis confirmed that the implant was made of Ti6Al4V alloy. After the metallographic preparation, the microstructure was evaluated on a NEOPHOT 32 light microscope and...
TESCAN VEGA LMU2 scanning electron microscope, which includes an EDX analyzer. Faults in the defectoscopy analysis were investigated using VGStudio MAX 2.2 software from Volume Graphics.

Table 1. Chemical components of endoprosthesis

| Spectral analysis of endoprosthesis [wt %] |
|------------------------------------------|
| **Al** | 6.47 |
| **V**  | 3.94 |
| **Mn** | 0.002 |
| **Ti** | 89.20 |
| **Sn** | 0.0073 |
| **C**  | 0.0358 |
| **Cr** | 0.0128 |
| **Nb** | 0.0236 |
| **Mo** | 0.0156 |
| **Si** | 0.0194 |
| **Ni** | 0.0137 |
| **Fe** | 0.219 |

The Beznoska Trio implant was made of Ti6Al4V alloy according to ISO 5832-3. It is made in three variants - cemented, uncemented, and uncemented with the possibility of using different types of modular necks. The uncemented variant is sprayed in the upper third by plasma spraying with a bioactive layer of titanium oxide, which ensures biocompatibility. There is also a version with hydroxyapatite, which is the main component of bone [7]. The length of the stem depends on the individual needs of the patient and ranges from 115 mm to 150 mm. The width of the implant exists in 10 possible alternatives from 12 mm to 16.5 mm, depending on the width of the patient's femur. The examined implant was size 3, and thus its length was 125 mm and width 14 mm.

3 Results and discussion

3.1 Microstructure
Evaluation of the microstructure of the material was performed on samples from both parts of the prosthesis. The samples were metallographically prepared (Figure 1) by the method used for titanium alloys on a TegraPol-15 Struers automatic instrument. Samples were polished and etched with 10% HF for structure analysis.

![Microstructure](image1.png)

Figure 4. Microstructure of stem

The study of the microstructure confirmed the differences in the parts of the implant. The neck part of the endoprosthesis (Figure 5) was made by casting. The microstructure of the sample was polyhedral with fine grains. There was a predominantly equiaxed α phase with a small amount of irregularly shaped β phase at the grain boundaries of the α phase. From the present knowledge, the dependence of the
fatigue life on the lamellar α phase is known. The larger the lamella dimensions are, the lower the fatigue life of the alloy is [8]. The lamellae α had the same shape and size. On the contrary, the stem part of the prosthesis was made by forging. On the microstructure, this was reflected in grain elongation and visible line spacing even at lower magnifications.

3.2 Defectoscopy

In the images, cracks are visible in the material occurring in an angular range of approximately 140 °, on the side facing the hip socket (Figure 1). An example of one of the cracks is marked by a red cursor in three planes and in space. The crack was formed at the place with the highest concentration of stress. Production inaccuracies caused imperfect fitting of endoprosthesis components.

Figure 5. Microstructure of neck

Figure 6. Description of the selected crack
There are strict requirements for accuracy in the production of a cone. However, a cavity is evident at the interface between the femoral neck and the stem, confirming that the two segments do not fit together correctly. The micro-movements in the conical part of the neck led to movements under load, which disrupted the passivation layer of the titanium alloy and initiated the crack. Another material marked with orange arrows is also visible (Figure 3). It is a physiological material from the patient's body that has reached the interface between the neck and the stem. Either by insufficient drying during implantation or along a crack in the micro-movements of the neck. The green arrow indicates beam hardening, which is an artifact created during scanning when the absorption of soft radiation on a surface gives the impression that the surface has a higher density. The defect is shown in the lower part of the joint, marked by an orange arrow (Figure 7). The defect extends into the neck, as well as into the hip part of the prosthesis.

The above analysis shows that there are no defects in the monitored area that the software could identify. The cracks described are either surface-exposed or too "thin" to be identified. Due to the lack of information on the initial state, it is not possible to confirm from the point of view of CT analysis whether they were already there before implantation. However, according to the direction of their orientation and their distribution, it can be assumed that they were formed during use by cyclic stressing of the material. Other defects represent damage to both parts of the endoprosthesis, as well as defects at the interface of the prosthesis components.

4 Conclusion

The results of the dissertation project suggest that despite the excellent mechanical properties, hip endoprostheses made of titanium alloys are damaged. An analysis of the current issue of premature failure replacements leads to the conclusion that titanium alloys have the most suitable application as replacements in the human body.

- Spectral and EDX analysis confirmed that the experimented material was a Ti6Al4V alloy.
- Analysis of the microstructure of the femoral stem and modular neck confirmed differences in their microstructure. The resulting visible differences were caused by different processing of the
material. The linear row structure represents the forged stem part of the endoprosthesis. The neck part is represented by a cast microstructure with dendritic elements.

- The main causes of prosthesis failure include manufacturing inaccuracies and micro-movements at the neck-stem interface. At these points, the stress is concentrated, and a fatigue crack is formed, which leads to material failure. The largest micro-movements were observed at the lateral edge of the conical connection of the stem and neck, which is consistent with the location of the cracks. In the case of normal walking, the life of the damaged implant is long, but at higher loads (running, climbing stairs) the life of the implant is significantly shorter.

- The location of crack is on tensile side of the femoral component.

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