ANALYSIS OF LACK OF STABILIZATION OF THE CEMENTLESS ACETABULAR CUP OF THE ENDOPROSTHESIS HIP JOINT – MATERIAL ASPECT

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Abstract

One of the most frequently performed orthopaedic procedures in Poland and in the world is hip arthroplasty. Correct placement of the implant in the bone tissue and initially positive postoperative results do not determine the durability and effectiveness of the above method of treatment. The durability of an arthroplasty depends on many biological and biomechanical factors, and their importance in the process of creating aseptic loosening of implants is still being analyzed. Significant conditions results, among others, from the construction and mechanical properties of implants. In this study, the subject of the study was the cementless acetabular cup of the endoprosthesis hip joint removed from the body due to the need for revision surgery. The surface of the deimplanted cementless acetabular cup of the hip joint was analyzed after 3 years of implant exploitation using stereoscopic microscope OLYMPUS SZ61 and scanning electron microscope JEOL JSM-6610 LV, the chemical composition was analyzed using scanning electron microscope with an EDS type X-ray microanalyzer, phase composition on a SEIFERT T-T X-ray diffractometer. The reason for the removal of the cementless acetabular cup was its loosening, which occured due to the fracture of cementless acetabular cup without displacement of fractions. The solution of the clinical problem was to replace cementless acetabular cup with a cemented acetabular cup. Macroscopically, no signs of osseointegration process were found on the porous surface of the deimplanted cementless acetabular cup.

Keywords: Revision operations, hip arthroplasty, cementless acetabular cup, implant, microstructure

1. INTRODUCTION

Total hip arthroplasty is currently one of the most frequently performed orthopedic surgeries aimed at reducing pain and improving mobility. The essence of this procedure is to replace the damaged, natural hip joint with artificial elements. Contemporary cementless total endoprosthesis consist of: an acetabular cup with an insert, a stem and a modular head. The most common indication for this type of surgery are degenrative changes. Subsequently, they may include aseptic necrosis of the femoral head, podysplastic changes, fractures of the femoral neck, changes in the course of rheumatoid arthritis [1,2]. A good result and durability of arthroplasty depend on many factors. In 2019 alone, more than 59,000 hip arthroplasty were performed in Poland, and almost 600 of them were revision procedures after previous arthroplasty [3]. Already in the 90s of the last century, cementless acetabular cups covered with a porous titanium coating were introduced. The more developed surface provides a more stable primary anchorage of the implant, complementing the press-fit technique. The acetabular cup are covered with porous titanium coating in the process of vacuum plasma spraying and are intended to enable a permanent connection with the surrounding bone tissue by osseointegration. Thanks to specially developed technology, the produced coatings have a thickness about

0,3 mm and a porosity at the level of 40%, and the pore size is in the range of 50 to 200 μm, which enables direct bone apposition. The most serious complications of arthroplasty include septic and aseptic loosening [3,4]. Septic loosening of the implant is a consequence of infection within the joint. While, aseptic loosening is a result of the lack of osseointegration, i.e. permanent connection of the implant with the bone tissue. The occurence of osseointegration depends not only on the correct surgical technique, but also on the structure and properties of the components of the endoprosthesis. If there are signs of loosening, a revision operation is required. Revision procedures are more extensive, technically more difficult and burdened with a higher risk of complications. Therefore, efforts are still being made to improve surgical techniques and optimize the properties of implants used in primary surgery. The study analyzed the titanium acetabular cup of the endoprosthesis removed three years after implantation.

The content of the article may be of interest to both implant designers and manufacturers [5], as well as material sciences, for which the results will be an impulse for new searches, both in terms of coating and structure [6,7], material composition [8] and analytical methods, both experimental [9-11] and numerical [12-14]. It may also affect research in related pharmaceutical [15,16] and medical issues [17,18].

2. MATERIALS AND METHODS

Examples of currently used types of cementless acetabular cup are presented in (**Figure 1a**). The stable connection of the acetabular cup with the bone takes place in two stages – primary and secondary stabilization. Ensuring a good, press-fit fastening of implant depends on good bone quality and appropriate surgical technique. The anatomical position of the acetabular cup, its size as well as the conditions for recreating the joint pivot point should be taken into account. When installing the acetabular cup, its inclination, anteversion and embedment depth are taken into account. Natural acetabular should be properly prepared for implant placement. After the perimeter of the acetabular edge is visualized, the bone bed is prepared by milling with the correct angles of inclination. Milling allows to give the desired location and shape of the acetabular cup, remove the remains of articular cartilage and reveal the bleeding, subcartilage layer of bone. The gradual increase in the size of the cutters allows to achieve the planned location, size and shape of the bone bed. **Figure 1b** show the intraoperative preparation of the acetabular bone bed, while (**Figure 1c**) show the embedded cementless press-fit acetabular cup. All procedures must be performed in such a way as to recreate the individual anatomical conditions. The surface of acetabular cup, covered with a porous titanium coating, remains in constant contact with the bone tissue – as a consequence, with the participation of bone-forming cells under the influence of mechanical stimuli, it is permanently connected with the bone tissue. The metal implant is overgrown with bone, providing secondary stabilization. The stability of the prosthesis components is one of the basic conditions responsible for the proper functioning of the implant. The loosening of the acetabular cup remains a problem not fully resolved. In most clinical cases, it is mildly symptomatic. It has been proven that early loosening are a consequence of errors in the course of surgical procedures and results from improper placement of the prosthesis. Whereas, late loosening results from biological or mechanical causes. The etiology of aseptic loosening is defined as a consequence of the slow process of osteolysis of the bone tissue surrounding the implant. Sabokbar A., Pandey R. and Atkanasou N.A. as one of the reasons they mention wear particles from the articulation surfaces of the endoprosthesis, which precipitator in the joint and the surrounding soft tissues [4]. Their research has shown that the type of immune cellular response depends on the shape and size of the released molecules. **Table 1** presents aseptic loosening risk factors [2]. The material science analysis carried out includes research of the chemical and phase composition on the deimplanted acetabular cup of the endoprosthesis hip joint after three years of exploitation. The research material is a titanium cementless „plasmacup" acetabular cup in the shape of a hemisphere with a slightly flattened top, covered with a layer of porous titanium. The porous titanium was applied on the surface of the acetabular cup by plasma spraying. Plasma sprayed coatings are characterized by high adhesion, low porosity and excellent mechanical properties. A 55 years old female patient suffered an injury to the right hip as a result of a fall from her own height. Three years earlier, she underwent primary cementless right hip arthroplasty.

Performed X-ray examination showed a fracture of the right pelvic bone through the acetabular cup without displacement of the bone fragments and features of acetabular cup loosening of endoprosthesis. The loosening of the acetabular cup was confirmed intraoperatively and it was removed. There were no significant bone defects within the acetabular cup bone bed. Due to the presence of fracture, a decision was made to embed polyethylene cup using bone cement. The acetabular cup was analyzed in terms of determining the causes of the implant loosening. For this purpose, the acetabular cup structure was examined using the stereoscopic microscope OLYMPUS SZ61 as well as microstructural analysis using the scanning electron microscope JEOL JSM-6610 LV. The chemical composition of the acetabular cup was analyzed using a scanning electron microscope with an EDS type X-ray microanalyzer, while the phase composition of the tested acetabular cup was verified with the SEIFERT T-T X-ray diffractometer.

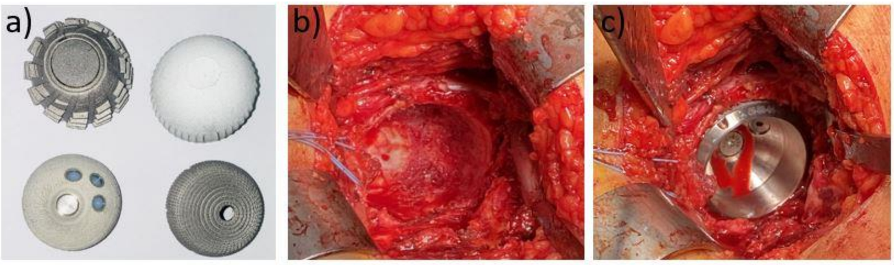


Figure 1 Macroscopic photos showing: (a) examples of cementless acetabular cup types, (b) properly prepared bone bed and (c) embedded cementless press-fit acetabular cup

Table 1 Aseptic loosening risk factors

Aseptic loosening risk factors:	
Depending on the implant used	implant model
	articulation used
	manufacturer
Depending on the operating technique	implant stability
	implant matching
	operator experience
	embedding technique
Depending on the healt of the patient	preoperative diagnostics
	physical fitness
	genetic predisposition
	comorbidities and body weight

3. RESULTS AND DISCUSSION

In the first stage of research, the structure of the deimplanted cementless acetabular cup was analyzed. **Figure 2** shows macroscopic photos of the examined implant. The conducted research revealed the places of surface violation of the implant resulting from the intraoperative removal of the acetabular cup from the bone bed. No features of the implant surface overgrowth with bone tissue were revealed. In order to visualize the components of bone tissue, research were carried out using the stereoscopic microscope OLYMPUS SZ61 – the results are presented in **Figure 3**. On the surface of the deimplanted acetabular cup, fragments of bone tissue were revealed, but only in a few places. The complete coverage of the implant with bone tissue and the features of the overgrowth of the implant were not visualized. The resulting bone tissue clusters were uneven and discontinuous. Large areas on the implant surface were revealed with no signs of coating.

Figure 2 Macroscopic photos of the acetabular cup surface: (a) front view, (b) rear view and (c) side view

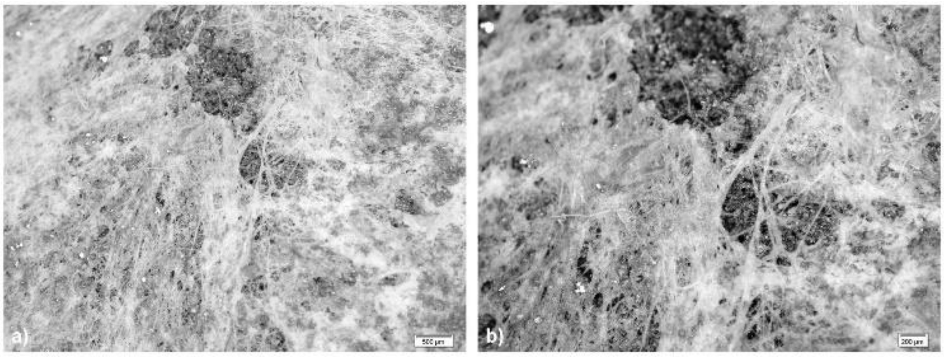


Figure 3 Selected fragments of the surface of the deimplanted acetabular cup

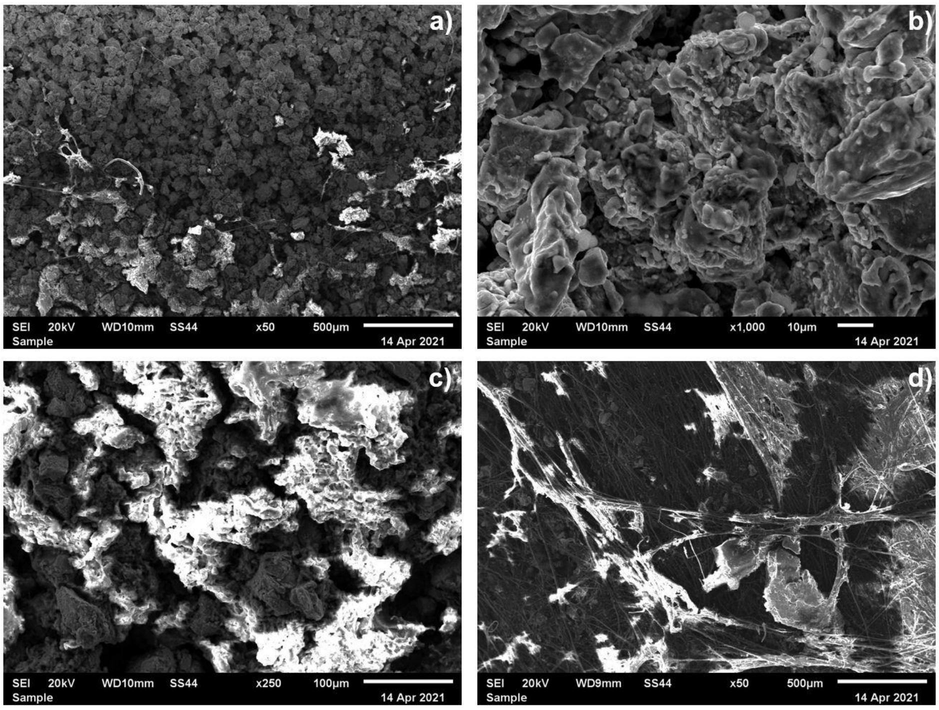


Figure 4 Photos of microstructures in selected places of the examined acetabular cup: (a) the boundary between the acetabular cup surface without bone tissue from the surface with visible bone tissue, (b) microstructure of the titanium coating, (c) visualized bone tissue – 250x magnification and (d) visualized bone tissue – 50x magnification

Table 2 The chemical coposition on the acetabular cup surface without any signs of bone cover

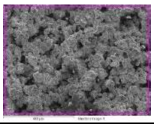
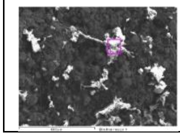
	Element	Ti	O	C	Ca
	Content [weight%]	78,36	13,09	8,12	0,42

Table 3 Chemical composition on the surface with visible bone tissue

	Element	C	O	Ca	P	Ti	Na	S	Cl	Mg
	Content [weight%]	43,47	28,17	16,91	7,85	2,21	0,51	0,39	0,29	0,22

The next stage of the research was to analyze the microstructure of the tested element. The obtained results are presented in (**Figure 4**). Using a scanning electron microscope with an EDS type X-ray microanalyzer, the chemical composition of the acetabular cup was analyzed in places covered with bone tissue and on the clean surface. **Table 2** shows the results of the chemical composition of the titanium surface without bone tissue cover, while **Table 3** shows the chemical composition of the visible elements of bone tissue. The chemical composition of the material remaining on the acetabular cup after reoperation confirms that it is bone tissue. However, the scant amount of material found indicates that there was no osseointegration and no secondary stabilization. Secondary stabilization occurs when bone tissue begins to overgrow the porous struture of the outer acetabular cup surface. After three years, most and often even the entire surface of the porous structure should be covered with bone tissue – however, this was not the case here. Next, the analysis of the acetabular cup phase composition was performed using a SEIFERT T-T X-ray diffractometer. **Figure 5** shows the diffractogram obtained for the examined acetabular cup of the hip joint. The X-ray diffractogram obtained for the acetabular cup revealed the presence of Ti_α and Ti_β phases.

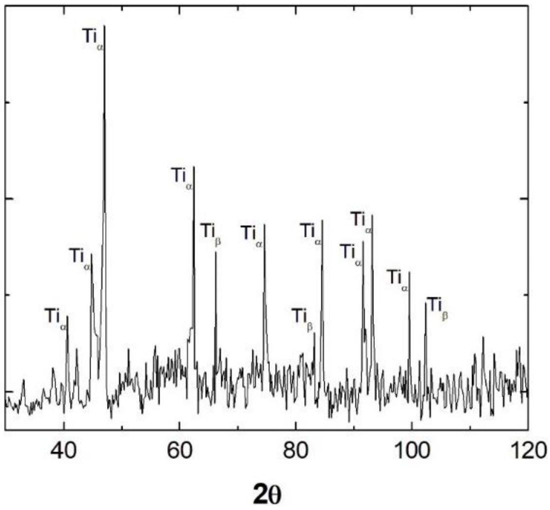


Figure 5 The diffractogram obtained for the tested acetabular cup

4. CONCLUSION

Hip arthroplasty is one of the most frequently performed orthopedic procedures. In most cases, these are elective operations aimed at improving the patient's comfort and quality of life. Considering that it is an invasive procedure, it carries the risk of complications that may level the good results of the procedure. According to the American Register of Endoprosthetics, among the complications determining revision surgery in recent years, 4,2% were aseptic implant loosening. The material science studies were carrried out on the deimplanted acetabular cup of hip joint endoprosthesis three years after implantation. Microstructural examinations did not reveal any signs of the overgrowth of the implant surface with bone tissue. The analysis of chemical composition confirmed the presence of bone tissue components on the implant surface. Nevertheless, the small amount of material found indicates that the process of osseointegration and secondary stabilization did not take place. Phase composition studies using X-ray diffraction revealed the presence of Ti_α and Ti_β phases, which confirms that the tested acetabular cup is made of a titanium alloy with a coating of porous titanium.

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