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Original paper

Parameters of unimplanted and explanted surfaces of Weller endoprosthesis stems

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40 samples of stem surfaces of the Weller endoprosthesis of hip joint removed because of aseptic loosening were tested. The patients between the ages of 61 and 87 were examined and the exploitation time of endoprosthesis ranged from 1 to 20 years. The material analysed was as follows: I group – exploitation 1–3 years (5 surfaces), II group – exploitation 5–8 years (11 surfaces), III group – exploitation 10–14 years (14 surfaces), and IV group – exploitation 16–20 years (10 surfaces). Additionally group 0 covered 4 unexploited endoprostheses. We analysed the 2–4 mm^2 surfaces of the Weller endoprosthesis stems, with the scan velocity of 500 μm/s. A decrease in stem amplitude parameters means some increase in stem microdisplacements in relation to cement. During the first three years, the decrease in the roughness of endoprosthesis surface was larger compared with that in further exploitation period. In the case of unexploited surfaces of stems, the values of fractal dimension are lower (2.34). During exploitation time the *Sfd* parameter decreases negligibly (2.28–2.24).

Key words: *Weller endoprosthesis, aseptic loosening, parameters of stem surfaces*

1. Introduction

In implanted cement endoprosthesis of hip joint, it is possible to observe two basic friction pairs: "cup–head" and "stem–cement". Life of tribological pairs and biological processes are of a vital importance for endoprosthesis stability [1]–[6].

The cyclic loads acting on endoprosthesis and interactive loads observed during walking cause some dislocations of stem versus cement [2]–[4], [6], which is responsible for stem wear [2], [3], [6], [7]. Under physiological conditions, those dislocations approach 1 μm [3], [4], [8].

In scientific literature, the authors do not find any papers dealing with the surface geometry parameters for stems of hip artificial joints under normal conditions. Other researchers often present some investigations, which refer to the roughness parameters and wear of endoprosthesis cups and heads of hip joints under laboratory conditions [9]–[13]. Based on some removed endoprostheses the authors analysed the influence of their exploitation time on some selected parameters of the surface geometry of the Weller endoprosthesis stems. In Poland, this endoprosthesis is often aseptically loosened, hence it has to be removed [2], [3], [14], [17].

The Weller endoprosthesis, as numerous artificial joints, is made from Vitalium alloy (i.e. Protasul-2, Mikromed-1, Endocast, HS–21). During the exploitation of cement models of hip endoprosthesis made from Vitalium alloy the changes of surfaces parameters are similar. The analysis of the above problems allows our knowledge about some causes of aseptic loosening of cemented endoprosthesis of hip joints to be extended.

The presentation of some changes in the amplitude of surface parameters and also in fractal dimensions (*Sfd*) during the Weller endoprosthesis exploitation is the main aim of this paper.

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2. Material and methods

40 samples of stem surfaces of the Weller endoprosthesis of hip joint removed due to aseptic loosening we analysed. The patients were between the ages of 61 and 87 ($\bar{x}$ = 74.6; σ = 6.6), the time of exploitation of endoprosthesis ranged from 1 to 20 years ($\bar{x}$ = 11.0; σ = 5.6). The material analysed, taking into account the time of artificial joints exploitation, can be divided into the following groups:

- I group – endoprosthesis exploited form 1 to 3 years (5 surfaces),
- II group – endoprosthesis exploited form 5 to 8 years (11 surfaces),
- III group – endoprosthesis exploited form 10 to 14 years (14 surfaces),
- IV group – endoprosthesis exploited form 16 to 20 years (10 surfaces).

The measurements of the roughness parameters and fractal dimension of the Weller endoprosthesis stems were carried out in the Department of Manufacturing Techniques and Automatics of the Technical University of Rzeszów (Poland) by using Rank Taylor Hobson apparatus (model Talyskan 150). The surfaces ranging from 2 to 4 mm^2 were analysed under the endoprosthesis collar, with a scan velocity of 500 μm/s (figure 1). The data obtained were processed by computer, using TALYMAP Expert 2.0 program and MS Office Excel 2003.

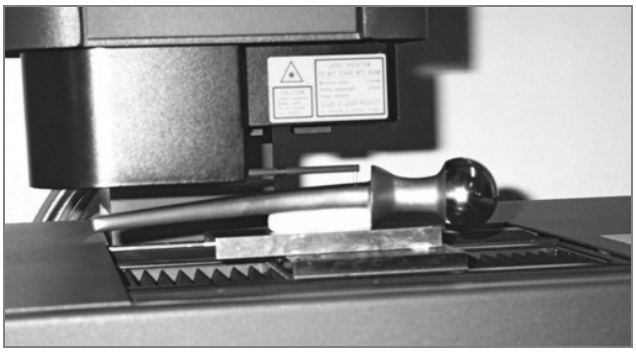

Fig. 1. Surface testing of Weller endoprosthesis stem

Rank Taylor Hobson apparatus allows us to measure over 20 surface parameters. In the investigations, the following parameters were chosen:

- Amplitude parameters:

total height of roughness *St* [μm] is defined as some distance between the highest point and the lowest surface depression in the testing area,

ten-point height surface irregularity *Sz* [μm] is a mean value of the absolute height of five highest peaks and five lowest depressions in the testing area,

mean arithmetic deviation of roughness *Sa* [μm] in the testing area.

- Fractal dimension of surface (Sfd).

Additionally, 4 unexploited surfaces of the Weller endoprosthesis stems, classified as the group 0, were subjected to scanning.

We determined a mean period of the Weller endoprosthesis exploitation and mean values of the parameters analysed in the groups under examination. Some dependence of the parameters analysed on the time of exploitation of the Weller endoprosthesis was also given.

3. Results

The relationship between the time of exploitation of the Weller endoprosthesis and the patient's age is shown in figures 2 and 3.

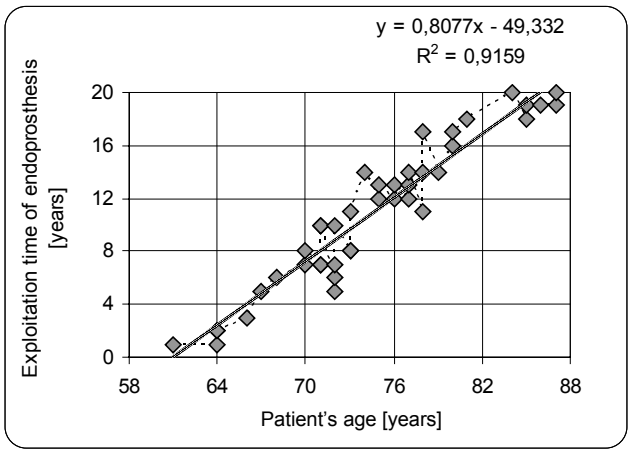

Fig. 2. Exploitation time of Weller endoprosthesis versus patient's age

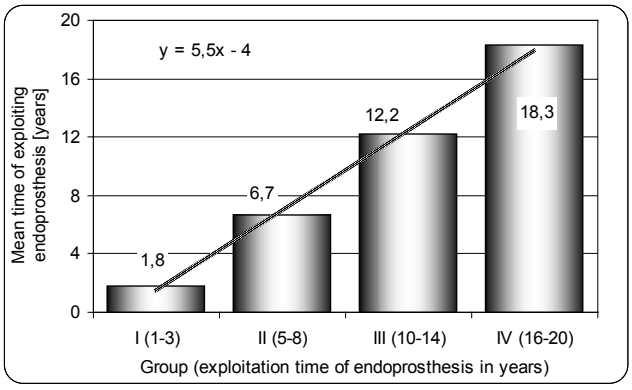

Fig. 3. Mean exploitation time of Weller endoprosthesis in groups under analysis

The older patient, the longer the mean time of exploitation of the Weller endoprosthesis. The trend line has some increasing character and is represented by the formula $y = 0.8077x - 49.332$. The value of the determination coefficient was high ($R^2 = 0.9159$).

The longer the time of observation, the longer the mean time of the Weller endoprosthesis exploitation. The trend line has some increasing character and is described by the formula $y = 5.5x - 4$.

The relationships between the parameters *St*, *Sz*, *Sa*, and *Sfd* and the time of exploitation of the Weller endoprosthesis are illustrated in the figures 4–7.

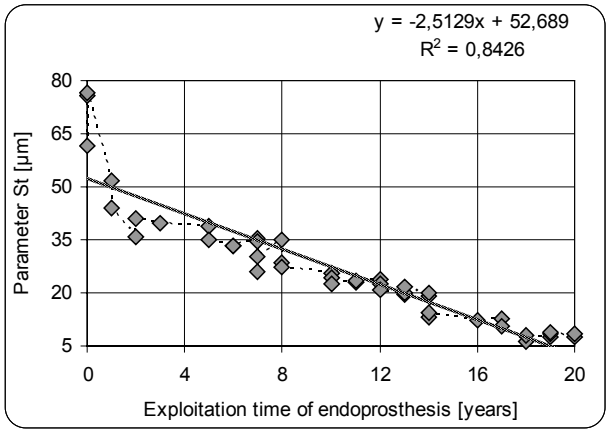

Fig. 4. *St* stem parameter versus exploitation time of Weller endoprosthesis

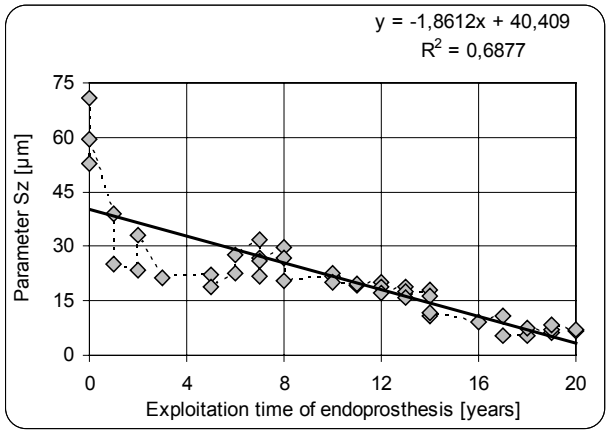

Fig. 5. *Sz* stem parameter versus exploitation time of Weller endoprosthesis

The highest values of the parameters *St*, *Sz* and *Sa* were observed on unexploited surfaces, while the lowest values, on the surfaces exploited for the longest time. The trend lines have decreasing character and are described by the formulae: $y = -2.5129x + 52.689$ for *St* parameter, $y = -1.8612x + 40.409$ for *Sz* parameter, $y = -0.2434x + 5.0756$ for *Sa* parameter. The determination coefficients have the following values: $R^2 = 0.8426$ for *St* parameter, $R^2 = 0.6877$ for *Sz*, $R^2 = 0.5427$ for *Sa*.

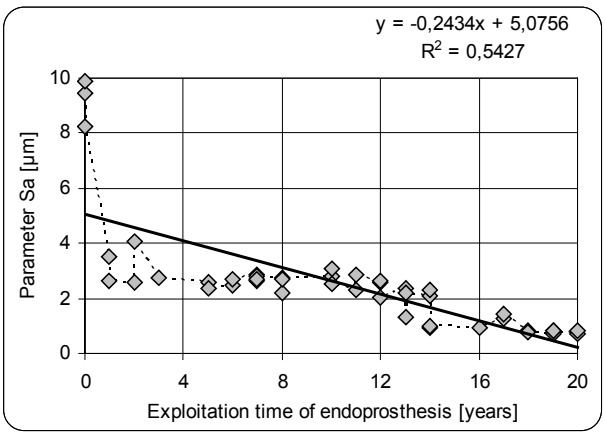

Fig. 6. *Sa* stem parameter versus exploitation time of Weller endoprosthesis

The dependence of the time of the Weller endoprosthesis exploitation on *Sfd* stem parameter is given in figure 7.

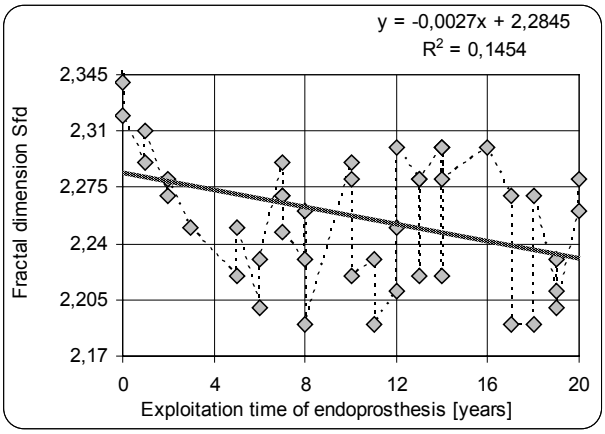

Fig. 7. *Sfd* stem parameter versus exploitation time of Weller endoprosthesis

The highest values of the fractal dimension *Sfd* were observed on unexploited surfaces of endoprosthesis stems, while the lowest values of that parameter – on exploited surfaces of stems. The trend line has a decreasing character and is represented by $y = -0.0027x + 2.2845$.

The determination coefficient R^2 is equal to 0.1454. The mean values of parameters *St*, *Sz*, *Sa*, and *Sfd* in the groups analysed are illustrated in figures 8–11.

The highest mean value of the parameter *St* was observed on unexploited surfaces of the Weller endoprosthesis stems. The trend line has a decreasing character and is described by $y = -13.97x + 76.57$. The

greatest difference in the mean values (i.e. 25.846 μm) occurred between the groups 0 and I. Moreover, in the rest of groups those differences were slighter (from 9.896 μm to 11.802 μm).

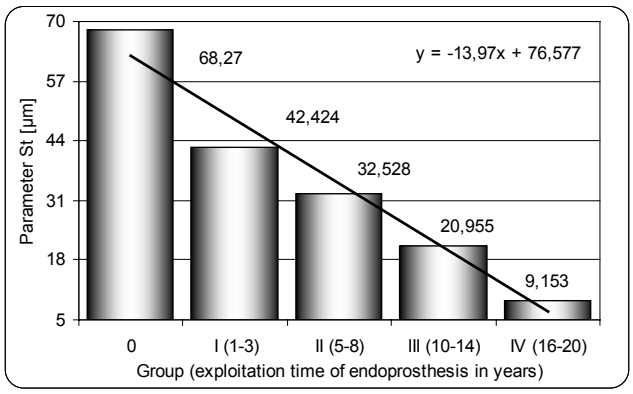

Fig. 8. Mean values of *St* parameter in groups analysed

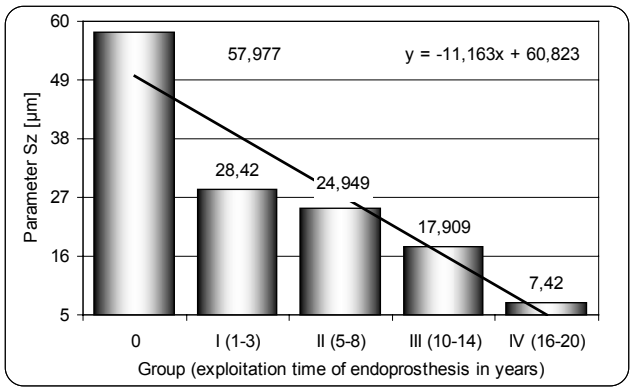

Fig. 9. Mean values of *Sz* parameter in groups analysed

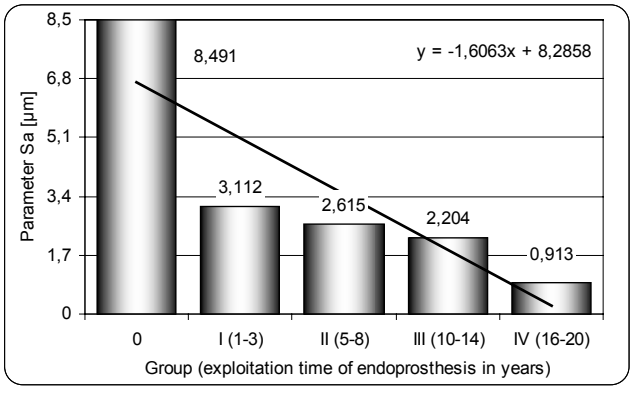

Fig. 10. Mean values of *Sa* parameter in groups analysed

The highest mean value of the parameter *Sz* was typical of unexploited surfaces of the Weller endoprosthesis stems. The trend line has a decreasing character and is described by $y = –11.163x + 60.823$. The greatest difference in the mean values (i.e. 29.557 μm) occurred between the groups 0 and I. Moreover, in the rest of groups those differences were slighter (from 3.471 μm to 10.489 μm).

The highest mean value of the parameter *Sa* was obtained on unexploited surfaces of the Weller endoprosthesis stems. The trend line has a decreasing character and is described by $y = –1.6063x + 8.2858$. The greatest difference in the mean values (i.e. 5.379 μm) occurred between the groups 0 and I. Moreover, in the rest of groups, those differences were slighter (from 0.411 to 1.291 μm).

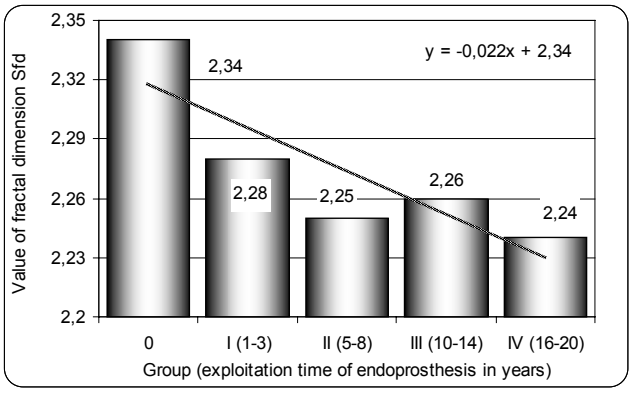

Fig. 11. Mean values of *Sfd* parameter in groups analysed

The parameter *Sfd* increased by its highest mean value on unexploited surfaces of the Weller endoprosthesis stems, its lower values were obtained on the exploited stem surfaces. The trend line has a decreasing character and is represented by $y = –0.022x + 2.34$. The greatest difference in the mean values (i.e. 0.06) occurred between the groups 0 and I. Moreover, in the rest of groups, those differences were even slighter (from 0.01 to 0.03).

4. Analysis of investigations and discussion

The maximum height of irregularities of the Weller endoprosthesis stems for the parameter *St* ranged from 58.879 to 76.555 μm and they were smaller than the values reported in paper [3], ISO standards [15] and Medical Techniques [16]. Microirregularities of unexploited hydroxyapatite-coated hip stem ranged from tens micrometers to 200 μm [3], [6].

The depth of the irregularities occurring on the surfaces of unexploited stems made from Vitalium alloy with or without carbon addition varied from 10

to 20 μm [3]. Unexploited surfaces of titanium stems are coated with microballs made from pure titanium with diameter from 3 to 5 μm [4], [6].

The surface irregularities of stems made from Co-Cr-Mo alloy are a few micrometers in height which is significantly less compared with our results [3].

Stem microdisplacements in relation to cement are caused by wear processes of both cement and stem [1]–[3], [7]. Cement, which is harder than metal, causes some decrease in local peaks of endoprosthesis stem (i.e. *St* parameter). That fact means some decrease in such roughness parameters as *St*, *Sz*, *Sa* and in fractal dimension *Sfd* of stems during exploitation of the Weller artificial joints. In the first years of the exploitation of the Weller endoprosthesis, some wear of stem surface was observed.

Microdisplacements of stem were also responsible for the abrasive wear of cement particles [2], [7]. Some marks observed were caused by stem displacements [7]. The smoothing of stem and cement surfaces shortens the life of connection of co-operating surfaces and decreases the stability of connection between cement and stem [2], [3].

Fractal dimensions of unexploited surfaces of stems are lower (*Sfd* = 2.34), and during the exploitation process the value of *Sfd* shows a downward trend (from 2.28 to 2.24). It is not observed any significant influence of the Weller endoprosthesis exploitation time on a decrease in fractal dimension ($R^2 = 0.1454$).

5. Conclusions

- During the exploitation process of the Weller endoprosthesis we observed some "peak smoothing" of surface irregularities of stems. That smoothing of the working peaks of stem and cement surfaces implies a worse stability of the "cement–stem" connection. The changes of such a type have some implication for aseptic loosening of endoprosthesis stems.
- A decrease in the amplitude of stem parameters is responsible for some increase in the stem microdisplacements in relation to cement. This fact means some possibility of aseptic loosening of endoprosthesis.
- During the first three years of using the Weller endoprosthesis the decrease in the roughness of its surface was larger in comparison with that occurring in further exploitation period.
- Unexploited surfaces of stems have the lower values of fractal dimension (*Sfd* = 2.34). During exploitation time the parameter *Sfd* negligibly decreases (from 2.28 to 2.24).

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