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# Investigation of Hip Joint Prosthesis Damage

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**A B S T R A C T**

*Following total hip arthroplasty the durability of a prosthetic implant depends on many factors but is generally limited by two types of damage: wearing of frictional surfaces of the acetabular and femoral component as well as the loosening and migration of the »prosthesis-cement-bone« system. Since it is possible to establish a cause-and-effect relationship between these two damage types, the aim of this research is to investigate the phenomena related to the contact surface and their influence on the prosthesis-bone relationship in general for various sizes and conditions of loading of the hip joint. The experimental study was conducted using a Timken testing device[1] modified in such a way that simulation of relative movements of the joint elements was achieved using a mechanism that produces conditions similar to those in the human hip joint. The analysis of obtained measurements showed that actual radii of friction of the hip prosthesis did not correspond to the theoretical ones and that only a small portion of the total friction surface is realized. Variations of the radius of friction for the examined prosthesis type were very large, which changes the hypotheses on the ability of the prosthetic head and the »prosthesis-cement-bone« system to bear a certain amount of load[2]. The construction and design of prosthetic implant components has a significant influence on both the amount of wear at the site of contact and the loosening of prosthesis.*

## Introduction

A relative change in the position of two objects in contact is not possible without forces large enough to resist the forces of interbody action. The force resisting a relative change of position is called frictional force. The effects of frictional forces are losses of energy spent on the friction and wear of materials in contact due to dynamic friction.

According to the majority of existing theories[3–5], the forces producing friction can be adhesional and deformational or have both adhesional and deformational properties (intermediary cases).

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Since the frictional force is proportional to the factor of friction it is essential to reduce the factor of friction[6,7]. This can be achieved by the separation of contact surfaces using an adequate lubricant whenever possible. The presence of a lubricating medium significantly reduces the factor of friction between contact surfaces as compared to direct surface contact. The medium can have various states of matter, including mixed states as well. With regard to the lubricating medium between two surfaces in contact we speak of three completely different states of lubrication:

- boundary lubrication with thin layers of lubricant on contact surfaces that can be removed only with chemical agents. This thin lubricant layer is attached to the surface by strong molecular forces and cannot be removed mechanically. A typical example are greasy surfaces or cases where the remaining lubricant is being squeezed out (large loads, the moment of resumed motion). With regard to the molecular thickness of the boundary lubricant layer, the factor of friction depends not only upon the properties of the applied lubricant but also upon the quality of contact surfaces,
- hydrodynamic (fluid) lubrication where contact surfaces are separated by a boundary layer and a layer of fluid lubricant thicker than the height of rough surface,
- mixed lubrication that comprises both boundary and fluid lubrication. A typical example for this is friction during motion in the presence of a lubricant. At rest, there is only a boundary lubricant layer whereas the increase in the relative speed of frictional surfaces results in fluid friction. This is the case especially in cinematic pairs with reversible motion at relatively small speeds, which is the subject of this study. Static friction appears at the moment of resumed motion when the speed is zero.

Roughness of contact surfaces is another factor influencing the reduction of friction. Therefore, it is essential that artificial joints have as low values of contact surface roughness as possible since the application of high quality lubricants is not possible. On the other hand, the roughness of the prosthesis stem (femoral component) is desirable[8,9] because of a better connection between the cement and the bone.

The third way of influencing the reduction of friction is material coupling. This has a crucial impact especially in case of deficient lubrication or even failed lubrication. The coupling of steel and artificial materials has proved to be a highly favorable combination for this particular case.

The fourth way of friction reduction depends upon the degree of mechanical stress related to normal daily activities and characteristics of the patient[10–12].

## Materials and Methods

The Ring total hip prosthesis was tested. Only one of two extreme types of motion was examined, namely torsional swinging motion of the acetabular component as compared to the femoral component of the hip prosthesis, which is most significant for the loosening and wear of hip prostheses. Changes in roughness as the parameter of wear and friction in time were measured for the input parameters of loading, speed flow and roughness. The actual radius of friction was also determined. The input parameters of loading and speed were set in order to reflect the extremely unfavorable conditions influencing the hip joint function. Axial loading force measured 2000 N and the maximum speed was about 1 m/s.

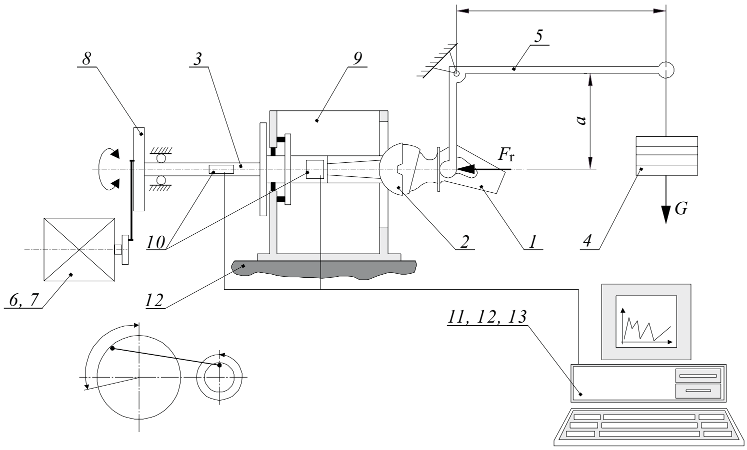


*Fig. 1. The scheme of the testing machine. 1-the lower part of the prothesis (femural part); 2-the upper part of the prothesis (acetabural part); 3-tensometric measuring shaft; 4-loading weights; 5-lever mechanism; 6-Propelling motor; 7-gearing; 8-mechanism for motive power; 9-housing; 10-tensometric tapes; 11,12,13-measuring amplifier and computer*

A special testing machine for loading and simulation of motion of prosthesis components was designed for this study. Upon Figure 1 the scheme of the trial device is represented.

Trials were performed with four lubrication types: dry, water, plasma and the light oil. The femoral component was loaded using the system of levers and weights. The acetabular component was fixed to the driven part of the testing device that could either move in circles at any rotational speed or oscillate at various speeds and angles of rotation. The sign of speed always changed, i.e. the cycle of motion and stopping was always maintained. This is highly significant since the setting in motion is most critical and it causes the largest forces of friction and consequently the largest frictional moments that are transmitted onto the femoral part of the prosthesis-bone system. Measurements of frictional moments, used to calculate other frictional parameters, were accomplished using a tensometric measuring system connected to a computer.

## Results

Based on the described procedure of loading and depending upon the preset conditions (forces and speed), the course of changes in the size of frictional moment within the joint was examined as the measure of resistance to the relative motion of joint parts. The results are shown in Figure 2. An abrupt increase in the size of frictional moment is seen with each change of motion direction as well as of the sign of sliding speed. The radius of friction was also measured based on the size of actual contact area: it measured 8

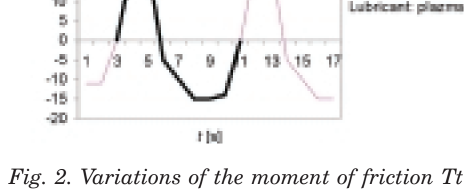


*Fig. 2. Variations of the moment of friction Tt during one cycle.*

mm at the point of largest wear of the prosthesis head as compared to the theoretical radius of friction measuring 27 mm (Figure 3).

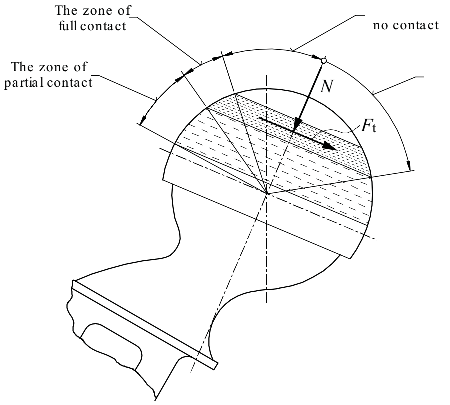


*Fig. 3. The scheme of loading and contact zones of the hip prosthesis.*

Figure 4 shows the results of measuring surface roughness in relation to the distance from the pole of the prosthesis head. There is an abrupt change of roughness in the zone of highest loading followed by a slow decrease parallel to an increase in the polar distance, which is also visible in Figure 5.

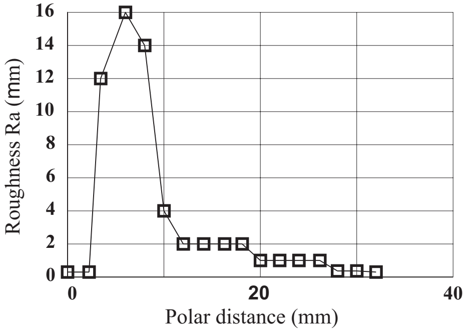


*Fig. 4. The results of measuring surface roughness of the prosthesis.*

## Discussion and Conclusion

It has been shown that the values of frictional moment obtained in an experimental study largely depend upon the applied lubricant and the amount of loading. A significant deviation of the actual radius of friction from the theoretical one shows the possible effect of precise design on the size of the torsional moment. An especially unfavorable influence occurs at certain points of contact of spherical surfaces (probably due to functional cleansing within the joint). Although such a positioning of spherical surfaces is rather rare, it should be pointed out that in such a case the torsional moment can be enlarged by several times.

*Fig. 5. The damage of the tested prosthesis.*

The control of surface roughness preceding and following the experiment shows that certain portions of the spherical surface are not involved in the process of friction despite excessive loading. This can be explained by incorrectness as well as intentional deviations of geometry for the purpose of improving the conditions of lubrication. Based on the obtained results it is possible to analyze the effects of torsional loading on the loosening within the »prosthesis-cement-bone system«.

In all testing combinations the graph of the bearing and the zone of contact were much smaller than theoretically possible even with highest loads (Figures 3 and 4). It can be assumed that the zone of contact would increase parallel to the increase in loading, but this did not occur. In fact, the greatest loading was transmitted onto an 8-mm wide spherical zone. This can be convenient only for a small polar distance when avoiding contact at one point, which would increase torsional moments. It should be also noted that the centricity of prosthesis components remained constant during testing, which under real conditions is not necessarily so as described[13,14].

Consequently, a change in the course of roughness appeared logical. In the zones of no contact the values of roughness did not change as compared to the initial roughness. In the zone of contact roughness increased abruptly up to $R_a = 16$   m and remained equally high (polar distance from 3–10 mm). This increase was caused by the destruction of contact surfaces in the presence of large frictional forces and was visible to the naked eye (see Figure 5). However, based on the measurements of roughness, another zone of contact was found, namely a zone of partial contact. It is obvious that it was taking over a smaller portion of loading, so that roughness values were several times smaller than in the zone of contact. This zone extended from the preceding zone up to the polar distance of 25 mm.

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## ISTRAŽIVANJE OŠTEĆENJA ENDOPROTEZE ZGLOBA KUKA

## S A Ž E T A K

Nakon operativnog zahvata ugradnje umjetnog kuka njegova će trajnost biti ograničena pored ostalog s dvije vrste opterećenja: trošenjem tarnih površina acetabular-

nog i femoralnog dijela kao i rasklimavanjem i migracijom veze sustava endoproteza-cement-kost. Kako ove dvije vrste oštećenja mogu biti u uzročno-posljedičnoj vezi cilj je istraživanja za različite veličine i uvjete opterećenja zgloba istražiti pojave na kontaktnoj površini kao i njihove refleksije na vezu proteze i kosti općenito. Istraživanje je provedeno eksperimentalno na prilagođenom Timken uređaju[1]. Prilagodba se sastojala u tome da je simulacija relativnih kretanja elementa zgloba ostvarena mehanizmom koji ostvaruje slične uvjete kao i kod realnog zgloba. Na temelju mjerenja pokazalo se da stvarni radiusi trenja endoproteze ne odgovaraju teoretskom, te da se od ukupne površine trenja stvarno ostvaruje samo mali dio. Odstupanje radiusa trenja za ispitivanu endoprotezu bila su vrlo velika, što znatno mijenja pretpostavke o opteretivosti kako glave proteze tako i veze endoproteza-cement-kost[2]. Konstruktivno je moguće, oblikovanjem dijelova endoproteze, utjecati na radius trenja sfernog dijela endoproteze. Time se može utjecati i na trošenje na mjestu kontakta i na rasklimavanje proteze.