ORIGINAL PAPER

CONTRIBUTIONS TO THE IMPROVEMENT OF THE TRIBOLOGICAL BEHAVIOUR OF HIP IMPLANT JOINTS

SIMONA MIHAI[1], VIVIANA FILIP[2], MIRCEA VLADESCU[2]

Manuscript received: 11.02.2016; Accepted paper: 02.04.2016;
Published online: 30.06.2016.

Abstract. *A hip implant is used when the natural hip joint (consisting in the hip bone and the femur) is affected and no longer able to perform its function. One of the main problems that arise when an orthopaedic implant is used is the wear caused by the friction that occurs in the joint. As the wear decreases the lifetime of the implant, which makes it necessary to replace it, research on methods of reducing the wear occurring in the joint implant will continue until this necessity is eliminated and the patient's locomotion can be performed as comfortably as possible. Therefore, the purpose of our work is to present the process of making and testing a hip implant joint prototype, where sliding friction is replaced by rolling friction, thereby reducing wear.*

Keywords: *joint, hip implant, friction torque, wear.*

1. INTRODUCTION

The locomotor system is the apparatus that enables the space movement and the mobilization of the various segments of the body, relative to each other. Functionally, it has two components: a static one, serving as supporting structure (the bones and their connecting elements them – the joints) and a second component, which mobilizes the static component – the muscles.

For over 50 years, numerous researchers have been studying design concepts, materials, and technologies intended to prolong the lifetime of hip implants. The literature includes an impressive number of publications related to this field. However, the ideal shape or material has not been found yet.

Whereas experience and medical statistics have shown that orthopaedic hip implants have a limited lifespan, requiring revision surgery, research continues on optimizing their design and choosing the best materials and execution technology with a view to reducing wear and decreasing the risk of dislodging [1].

Tests on new design concepts intended to improve hip implants were made by other authors, too. A test hip implant with tapered rolling elements around the femoral neck was put forward by the Imperial College of Science, Technology and Medicine in London [2]. Another version, proposed by Katsutoshi Bekki and Kiyoshi Shinjo, includes a "train of rolling balls" [3]. Another type of ball-based hip implant with a "clearing space" allowing the rolling balls a free self-directioning movement is proposed by the Institute of Solid Mechanics

[1] Valahia University of Targoviste, Multidisciplinary Scientific and Technologic Research Institute, 130004 Targoviste, Romania. E-mail: mihai.simona@yahoo.com.
[2] Valahia University of Targoviste, Mechanical Engineering Department, 130004 Targoviste, Romania. E-mail: v_filip@yahoo.com, vladescumircea2006@yahoo.com.

of the Romanian Academy, in collaboration with the University of Medicine and the University Hospital in Bucharest [4, 5].

The relative movement allowed by the joints play an important role in the load transfer from one bone segment to the other. The load transfer mechanism is based on the contact between joint surfaces, with all the consequences involved (friction, wear, etc.). Replacing a natural joint with an artificial one will subsequently affect the load transfer mechanism and will generally be conditioned by it, due to the fact that the components of the prosthesis must allow the relative movements specific to the full range of human activities for a long time [6].

In terms of wear mechanisms, the implants removed from patients have revealed a number of wear mechanisms, as follows: abrasive wear, third-body abrasive wear, adhesive wear, contact fatigue wear, corrosion wear and fretting wear. Depending on the loads applied to the implant, the afore-mentioned mechanisms combine at various times (not simultaneously), intensifying the wear process.

2. PAIRS OF MATERIALS USED FOR HIP IMPLANT JOINTS

The hip joint coupling options are not commercially available in a wide range of choices, as they are subject to the limitations imposed by the biocompatibility requirements of the materials used.

The most frequent combinations of materials used for hip implant joints are metal-on-polyethylene bearings (MoP), followed by metal-on-metal bearings (MoM), ceramic–on-polyethylene (CoP), and ceramic-on-ceramic (CoC).

A new version, so far studied only on a simulator, is ceramic-on-metal bearing (CoM). The ion levels measured in the serum samples were comparable to those measured in the case of the CoC combination and much lower than those measured on the MoM. Although these results were encouraging, there are no medium- and long-term clinical studies to support the use of CoM bearings [7].

MoP bearings are made of stainless steel and cobalt-chromium-molybdenum alloy (Co-Cr-Mo); titanium alloy is used as well. Laboratory studies on CoP bearings have shown less wear, but a high rate of fractures. CoC bearings, despite the advantage of being highly biocompatible, are low-ranked on the market as they tend to fracture too soon and they emit a disturbing creaking sound. MoM bearings have been used in orthopaedics for many years; a problem with some models is the imperfect tolerances in the manufacturing process. The studies performed using a simulator have demonstrated the importance of the spherical diameter tolerance (90-200μm) in facilitating the polar contact of the bearing and the access for serum lubrication [7].

3. THE PRESENTATION OF OUR DESIGN CONCEPT

To reduce the friction occurring in the joint and to increase the lifetime of the implant, we proposed replacing the sliding friction with rolling friction, which has a lower coefficient. The proposed option consists in inserting two ball cages. For each mechanical element of our concept we made a 3D-model using the SolidWorks software (Fig. 1.) so that the areas of interference between the components and the surfaces of reference for installation can be detected during the design phase.

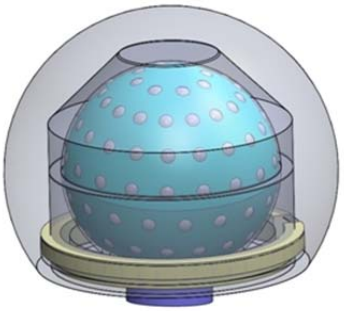

Figure 1. New design concept for the friction torque on the hip implant: the 3D-model of the assembly.

Fig. 2. shows the prototype created, which comprises: 1 - femoral neck; 2 - retaining ring; 3 - first ball groove; 4 - first ball cage; 5 - spherical proximal end of the femoral stem; 6 - second ball cage; 7 - second ball groove; 8 - femoral head.

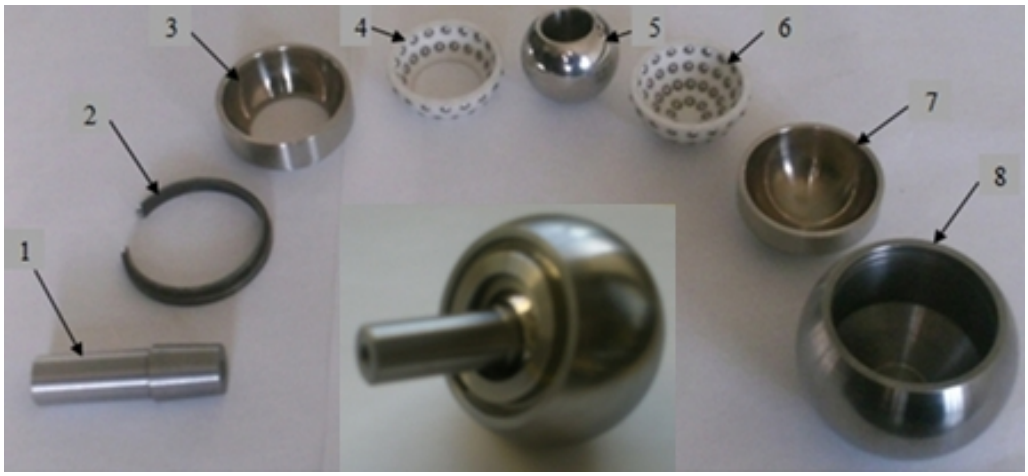

Figure 2. Prototype.

When manufacturing medical industry components, priority is given to the materials with the highest biocompatibility and corrosion resistance, while processability is the last selection criterion. The metal parts were made on the TL1 HAAS 2-axe CNC machine available at the Experimental Models, Prototypes and Unique Parts Department from the National Institute of Research and Development in Mechatronics and Measurement Technique (INCDMTM) Bucharest. In establishing the working conditions, we considered the following issues: the shape and size of the blank, the dimensional accuracy and the roughness of the surface processed. The cages were manufactured by powder-rapid prototyping at the "EOS GmbH - Electro Optical Systems" laboratory from Germany through Z Spot Media – a department dedicated to 3D equipment.

4. TESTING THE PROTOTYPE DEVELOPED AND A CONVENTIONAL IMPLANT

The prototype was tested at the Multidisciplinary Science and Technology Research Institute of Valahia University of Targoviste (ICSTM-UVT), Laboratory B05 - Prototyping and Eco-Design in Renewable Energy Systems, using a MTS Bionix axial load unit equipped with a hip test fixture, shown in Fig. 3.

Figure 3. MTS Bionix axial testing system equipped with a hip test fixture.

The MTS Bionix load unit was used to test firstly the prototype we developed and then a conventional implant (Fig. 4.).

Figure 4. Implants tested on the MTS Bionix load unit:
a) prototype, b) conventional implant.

In order to ensure the stability and precision of the response, we performed the command and response adjustments, using the "Station Setup" command, as shown in Fig. 5. As can be seen, both the command and the response display the same type of curve and are very close, the response overlapping the command, which shows that the system's adjustment is correct.

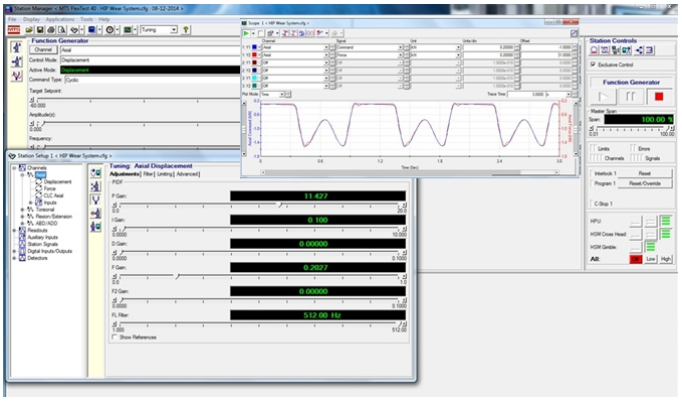

Figure 5. Load unit adjustment settings.

After making the command-response settings, we zeroed the output value for each axis (axial, torsional, flexion/extension, abduction/adduction) using the "Manual Controls" application.

The adjustment parameters of the unit are set using the "Station Manager" application and the testing program is set using the "Multipurpose Elite" software. The test parameters were set according to ISO 14242.

Fig. 6 shows the time graph of downforce (curve 1) versus moment of friction (curve 2) on testing the prototype developed, while Fig. 7 shows the time graph the downforce (curve 1) versus moment of friction (curve 2), on testing the conventional implant.

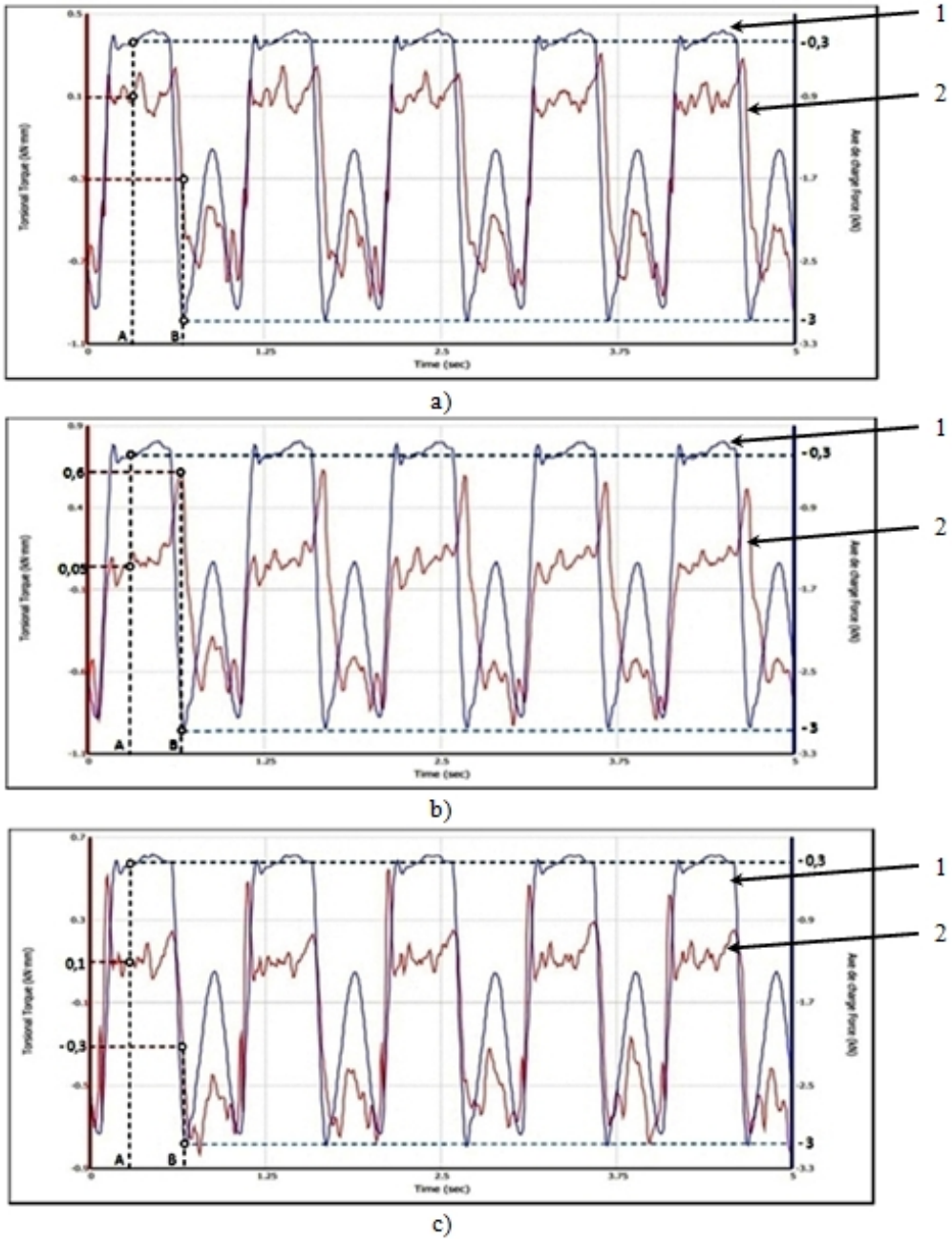

Figure 6. Time graph of downforce (curve 1) versus moment of friction (curve 2) on testing the prototype developed.

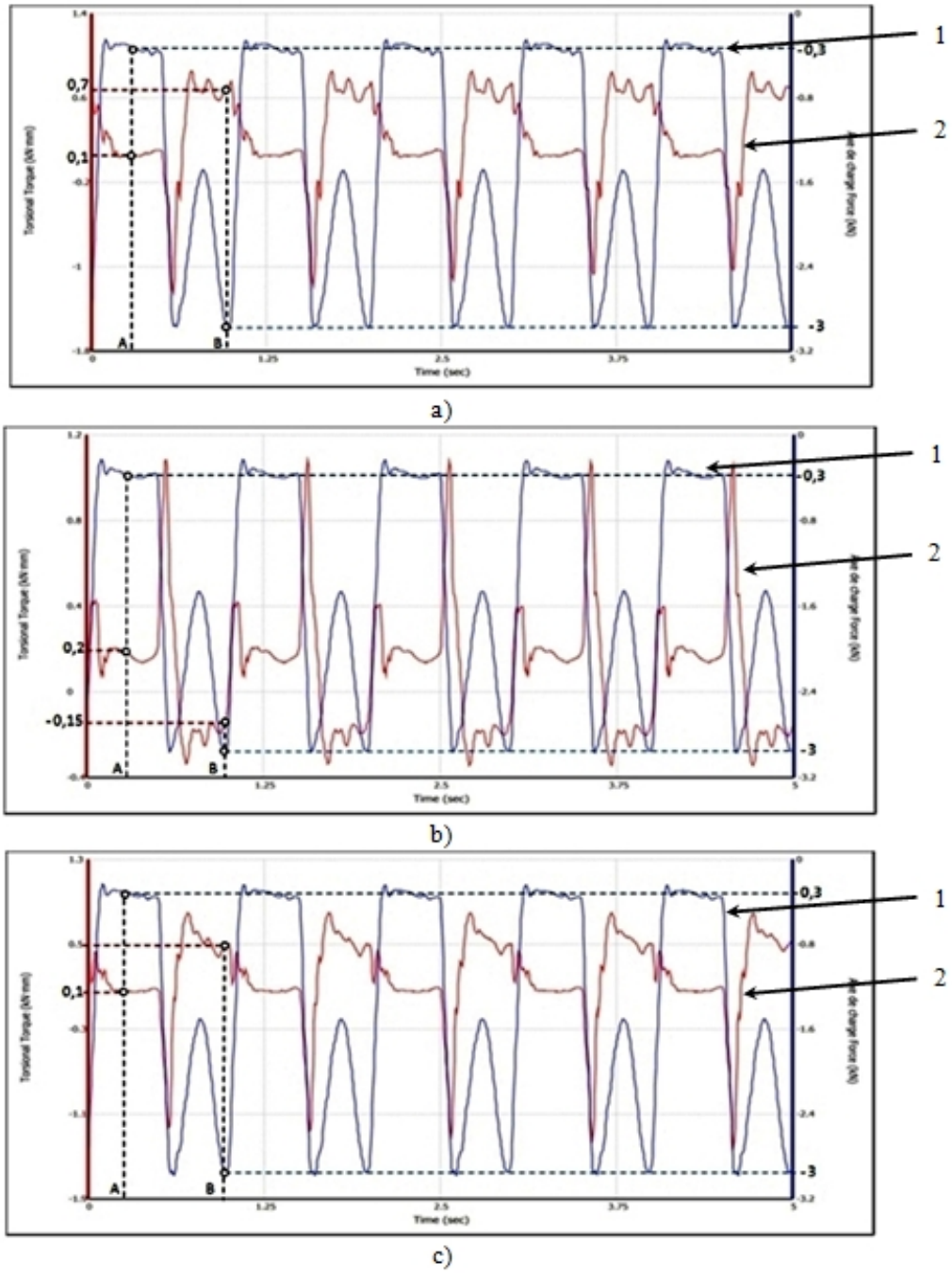

Figure 7. Time graph of downforce (curve 1) versus moment of friction (curve 2) on testing the conventional implant.

5. COMPARATIVE ANALYSIS OF THE RESULTS. CONCLUSIONS

The hip implant joint is a ball joint that is a spatial coupling of rotation allowing 3 degrees of freedom, representing the 3 rotations around the coordinate axes (ωx, ωy, ωz). Therefore, this coupling restrains 3 degrees of freedom, i.e. the 3 translation movements on the axes. As the number of movement restraints introduced by the coupling is 3, this means that it is 3rd class coupling. The restraints to translational movements on the 3 axes are imposed by forces X, Y, and Z (Fig. 8.).

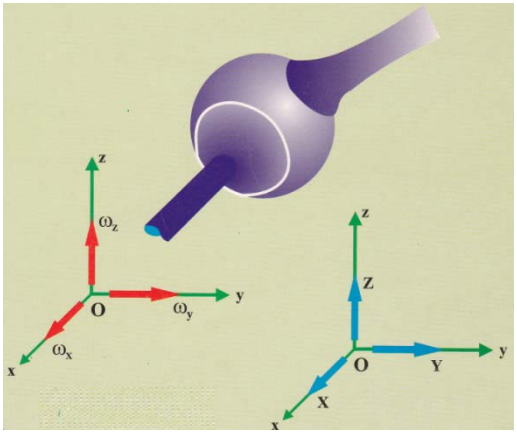

Figure 8. The rotational degrees of freedom and restraints to translational movements imposed by the ball joint [8].

The moment of friction occurring in a ball joint results from the following relation:

$Mf = \mu R F$

Where:

- Mf is the friction torque,
- μ is the friction coefficient,
- R is the joint's radius (in our case R = 14 mm = 0,014 m)
- F is the resultant of forces X, Y, Z exerted on the joint (in our case, the normal downforce applied to the joint, whose values were set at a minimum of 0,3 kN and a maximum of 3 kN).

Table 1. Friction coefficient values measured on testing the prototype we developed.

Graph	Point	F [kN]	M [kNmm]	μ
Figure 6 a)	A	0,3	0,1	0,0238
	B	3	0,3	0,0072
Figure 6 b)	A	0,3	0,05	0,0119
	B	3	0,6	0,0143
Figure 6 c)	A	0,3	0,1	0,0238
	B	3	0,3	0,0072
			μ mean value	**0,0147**

Table 2. Friction coefficient measured on testing a conventional implant.

Graph	Point	F [kN]	M [kNmm]	μ
Figure 6 a)	A	0,3	0,1	0,0238
	B	3	0,7	0,0167
Figure 6 b)	A	0,3	0,2	0,0715
	B	3	0,15	0,0036
Figure 6 c)	A	0,3	0,1	0,0238
	B	3	0,5	0,0119
			μ mean value	**0,0253**

The results of the tests performed on both implants show that the friction coefficient measured on the prototype we developed is lower than the friction coefficient measured on of the conventional implant (Table 1 and Table 2).

Replacing the sliding friction specific to conventional implant joints with the lower coefficient-rolling friction, as in the case of the prototype we developed, results in reducing the friction torque and, therefore, less wear on the implant.

Furthermore, following the wear tests performed, we have found that an amount of fine white polyethylene powder came off the conventional implant: if reaching the human body, this amount of powder would cause inflammation and tissue necrosis and would send the patient back to the operating table for revision surgery and reimplantation.

REFERENCES

[1] Mihai, S., Filip, V., *Applied Mechanics and Materials*, **658**, 453, 2014.
[2] Sadeghi-Mehr, M., *Investigations of Rolling Element Bearing for Hip Joint Prosthesis*, PhD Thesis, Imperial College of Science, Technology and Medicine University London, 1977.
[3] Katsutoshi, B., Kiyoshi, S., *US Patent 5092898*/30.03.1992.
[4] Capitanu, L., Florescu, V., *American Journal of Materials Science*, **2**, 185, 2012.
[5] Capitanu, L., Florescu, V., Badita, L., *Preliminary Studies regarding Load Transfer Mechanism in MOM Total Hip Prostheses with Rolling Balls*, Proceedings of 13th International Conference on Tribology - Serbiatrib'13, 331, 2013.
[6] Badita, L.L., *Contributions regarding improvement of tribological characteristics of hip implants by nanodepositions of biocompatible materials*, PhD Thesis, Institute of Solid Mechanics, 2012.
[7] Guy, T., Williams, Mc., Parker, J.R., *Orthopaedics and Trauma*, **1**, 2, 2009.
[8] Zaharia, S.E., Atanasiu, M., Filip, V., *Mecanica. Aplicatii in inginerie. Statica*, Vol. I, Niculescu Publishing House, Bucharest, 2000.