A surprising tribological validation: metal on metal total hip prosthesis with rolling friction

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ABSTRACT

The paper reports about the validation studies of the mode of functioning of a metal on metal (MoM) total hip prosthesis (THP) with rolling friction, obtained by introducing a number of balls between the femoral head and acetabular cup. After over 15 years of research upon the functional principle and constructive solution a final version that offered a coefficient of minimum friction in the hip joint came to light. This version was based on a constructive solution of motion with lower friction, “Omnitrack® movement solutions”, which has been modified and rebuilt to be used as a joint of a total hip prosthesis-MOMJ. The prosthesis was built entirely in stainless steel, SS316L medical grade. Tests have been carried out on the experimental laboratory devices that showed very low values of the coefficient of friction (0.0225). For validation, the prosthesis had to be put through tests for 50000 cycles, in terms of physiological motion and dynamic loading, according to ISO 14242-3. Testing was conducted on a multiaxial dynamics machine, MTS Bionix, equipped with system for hip implant testing. The testing results of this total hip prosthesis with rolling friction have been successful in signing up for a friction moment of 0.525 (kN·mm) which means a coefficient of friction of $\mu = 0.0143$, for a joint with femoral head diameter 28 mm.

Keywords: Total hip prosthesis, rolling friction, balls, femoral head surface wear, Omnitrack® movement solutions, validation by laboratory testing.

1. INTRODUCTION

In over 20 years of research in the field of loosening and wear of orthopedic endoprosthesis, the authors conducted research from a tribological view oriented to the screening of the causes determining the failure of the prosthesis removed after replacement surgery. Multiple causes have been identified including the loosening of the cemented stems, breakage of the press-fitted stems, femoral heads scratching due to particles of cement, bone or peeling coatings thin layers of femoral heads, embedding of wear particles in acetabular cups surfaces, etc. Pending its function the femoral head of a total hip prosthesis suffered a series of damages in the human body leading eventually to the failure of the prosthesis. Current practice in the manufacture of total hip prosthesis is to make a base alloy femoral head in order to take over the mechanical forces, with a monolayer covered surface or multilayer hard coatings, friction and wear resistant. Co-Cr and titanium based alloys (Ti6Al4V) are the most used materials. The physical characteristics of titanium, the strength, hardness, high durability, low density, corrosion resistance and biological compatibility, make it useful in a variety of biomedical applications. Titanium in the form of thin film is used to protect or improve the surface properties of various materials. Many applications of titanium thin films require knowledge of its tribological behavior. Ti-6Al-4V alloy has excellent corrosion resistance, biocompatibility, high strength in relation to its weight and also a great tenacity, for these reasons it is an alloy widely used for advanced biomedical applications [1]. However, the tribological properties of these alloys are known to be weak, especially in abrasive and sliding [2]. Several surface treatments pursuing to improve tribological properties of this alloy, including plasma nitriding [3], ion implantation by plasma immersion [4], laser nitriding [5], physical vapor deposition (PVD) [6] were taken on board. Among various processes, PVD coatings can be produced at lower temperatures and therefore it has the advantage of fewer adverse effects on mechanical properties of the substrate. Many studies have been produced regarding Ti-6Al-4V alloy coated with either a single coating [7-8] or by duplex approach that increases the load borne by the substrate: nitriding TiN [9], HVOF WC-Co/TiN [10], nitriding/DLC [11], deep hardening oxygen/ DLC [12].
Tribosystem friction properties strongly depend on the properties of materials, the external environment and the nature of the wear particles generated during sliding [13]. The way a surface is deformed, will dictate the nature of the wear particles generated, which in turn can significantly influence the wear behavior of materials. The tribofilms and wear particles generated during sliding are known to influence the behavior of the materials friction [14]. Tribological mechanisms describe the macro-mechanical friction and wear phenomena by taking into account the distribution efforts - strains in the entire contact, total elastic and plastic deformations, formation process of the wear particles and its dynamics [15, 16].

More recently, it was analyzed the effect of different mating materials on friction behavior of TiN coatings with different crystallographic orientations [17]. It was noted that the formation of a titanium oxide layer on the surface leads to a lower value of friction. Many researchers aimed at studying the tribological behavior of pure titanium metal and titanium alloys [18-19]. But reports on the wear behavior of Ti thin layers are rare. Since titanium nitrides are hard biocompatible materials [20-22] with excellent resistance to abrasion, have been developed more advanced processing methods in order to achieve a nitride layer on the surface of materials. At the presence of nitride in plasma [23], nitrogen atoms diffuse into the titanium matrix, forming a layer of TiN and Ti2N compounds, usually followed by a deeper diffusion layer. This layered structure produces a continuous profile of hardness, thus providing adequate support of the coating [21, 24]. However, the physical properties of treated surface are highly dependent on plasma coating technique and processing parameters.

Excellent corrosion resistance of titanium alloys resulted in the formation of a stable protective oxide film very strongly adhering to metal surfaces [25]. On the other hand, the corrosion resistance of TiN can be affected by its structural defects (pores, holes and small cracks) [23]. In fact, Meletis et. al., [26], showed that an adequate structure without defects and dense TiN film can significantly improve corrosion resistance. Co-Cr-Mo alloy is one of the most used implant alloys for artificial joints and offers a good combination of mechanical properties, corrosion resistance and biocompatibility. However, many investigations on femoral heads removed after a replacement surgical interventions, showed numerous traces of wear on the surface of the prosthetic femoral head. In many studies [27-29] scratches, pits and coating peeling, sometimes even early traces of corrosion have been identified. Capitanu et al [27], reported their findings regarding the head of a femoral prostheses made from Ti6Al4V explanted after 10 years, from an athlete. They found severe deformation of it, but and cold hardening and in areas subject to cyclic compression. Due to this problems, theoretical and experimental research over the last 30 years have tried to contribute to the improvement of orthopedics endoprostheses durability, through constructive changes and even through changing their functional principle.

Total hip prostheses with wheels is one of the first attempts to decrease wear, by replacing the sliding with the rolling movement for one degree of freedom of the joint. This solution, suggested by researchers from the Imperial College of Science, Technology and Medicine in London, consists of the constructive modification of the modular hip prosthesis by introducing a rolling bearing with conical wheels between the femoral stem neck and the femoral head [29]. It has been considered that a rolling bearing with conical wheels, that can support significant radial and axial loads, is most adequate for reaching this goal. But this requires a small diameter of the interior ring, imposed by the necessity of a reasonable diameter of the femoral head. Ensuring a satisfactory resistance for the bearing to challenge fatigue is also necessary, and changeability of the femoral head is also imposed. Regarding these constraints, a cylindrical wheels bearing has been considered. One must notice that rolling bearings with needles present a great durability to fatigue. The simulation was performed for 3 million loading cycles. After the first 500,000 cycles, oxidation of the femoral head was observed, manifested through color changes. The color of the interior acetabular cup’s surface was also changed.

Other attempts regarding changing the constructive solution of total hip prosthesis took into consideration the fundamental change in the type of relative movement between the components of the total hip prosthesis. If, generally, the present technical solutions are based on the natural revolute movement of the femoral head in the acetabular cup, Katsutashi Bekki and Kiyoshi Shinjo [30] imagine a different design, the total hip prosthesis with „balls train“. This mainly consists of a dual joint construction. The artificial joint is composed of an interior sphere and an exterior cup restricting the movement of a train of balls mounted in a cage. By the characteristics of this design the movement is mainly by rolling.

The French idea of the “Supertête” prosthesis [31] consists of placing the friction contact inside a bearing. The solution belongs to “Fondation de l’Avenir” in collaboration with “La Direction Générale de l’Armement (Ministère de la Défense, Mission Innovation)”. In the opinion of French researchers, this technical solution can reduce the wear of the prosthesis with almost 99%. In order to reach this result, a small spherical bearing of an “absolutely new” type, as the authors claimed, lubricated with synovial fluid, the natural lubricant of any prosthesis, was integrated in the femoral head. Designed and built in accordance with aeronautics industry standards, the femoral head is claimed to have reduced wear, being designed to carry 25,000 N, while the hip joint maximal forces do not overpass 5,000 N. The authors estimate that this artificial joint is able to function more than 30 years for a frequency of loading of approximately 1 million of cycles/year.
Another kind of total hip prosthesis with balls is proposed by the Institute of Solid Mechanics, of the Romanian Academy, in collaboration with the University of Medicine, and the University Hospital of Bucharest [32-34], making the object of a Romanian Patent. Analyzing some hip prostheses retrieved by revision, the appearance of some forms of polishing of the femoral head was observed, as well as significant plastic deformations followed by local hardening. At the same time, obvious traces of wearing through fretting of the acetabular cup of UHMWPE, which in some studies are confounded or assimilated with the adhesive wear have been revealed. Starting with the well-known fact that the rolling movement always has a lower friction compared to sliding friction, the authors have conceived and realized a pivoting movement joint on a “layer of balls” with “compensation space”, placed between the acetabular cup and the femoral head. This technical solution allows free self-directed migration of the balls, depending on the resistance opposed, with successive occupation of the “compensation space”. As a concept, the proposed technical solution excludes the existence of a cage for maintaining the relative positions of the balls. This study targeted contact mechanism including friction and wear phenomena accounting.

The proposed hip prosthesis, with self-directed rolling bodies, was made using a femoral head from Stelit 21, the acetabular metallic cup from Ti6Al4V-ELI alloy and the balls from stainless steel. But experiments revealed a certain seizure in some strain conditions. The trials have been carried out in BSF (body simulated fluid) lubrication conditions, much closer to the real operating conditions up against the initial tests with distilled water. Laboratory trials for balls/plane Hertzian contacts have been restarted in order to determine seizure behavior depending on the roughness of the flat area [35]. This was the cause for which we have abandoned this constructive version, but not the idea of achieving a total hip prosthesis with rolling friction. That's why I selected a variant of motion adopted after Omni Directional Movement Solutions from Omnitrack™. This variant of the low friction movement ($\mu = 0.05$) in the ball bearing, was modified and adapted for use as constructive acetabular-femoral joint in a total hip prosthesis with the rolling friction (modified Omnitrack movement joint – MOMJ).

2. EXPERIMENTAL METHODS

Based on Omni Directional Movement Solutions from Omnitrack™ - Fig. 1 (a), a few hip joints with balls (MOMJ), using femoral heads from classical MoP prosthesis - Figs. 1 (b) and (c) have been made. The hip implant joint is a spherical joint, a spatial rotating couple with 3 degrees of freedom, representing the three rotations around the coordinate axes ($\omega_x$, $\omega_y$, $\omega_z$). Therefore, this couple limits the 3 degrees of freedom, i.e., the three translations on axes. Translational constraints on the 3 coordinate axes are materializing forces $W_x$, $W_y$ and $W_z$ - Fig. 1 (d).

![Figure 1](a) Stainless steel 316L Omnitrack™ joint with low friction ($\mu = 0.005$), maximum speed 2 m/s, high shock resistance. (b) View of the new joint, (c) Scheme of the new acetabular- femoral joint (MOMJ), based on a modified Omnitrack movement solution: 1 - balls guide; 2 - outside casing; 3 - superior handle; 4 - balls; 5 - lower handle; 6 – femoral head; 7 - silicone rubber liner; 8 - lid; 9 – “Spiralax” ring, and (d) Rotational degrees of freedom and movement restrictions imposed by the translation spherical joint

It can be seen from Fig. 1 (c) that at this joint, the loading is transmitted to the femoral head via of the 106 balls, made from 316L stainless steel – medical grade, and their movement is guided by a track of alumina ceramics with semispherical surfaces. The balls are moving freely in closed circuit between the two semispherical surfaces of the guide, external casing and femoral head. The inside guide of the balls is a femoral head of 28 mm diameter of a standard MoP prosthesis. In order to obtain the modified joint, the exterior component of the Omnitrack™ solution has been processed by turning so that it could fit into a medical grade 316L stainless steel casing and create the cocso – femoral prosthetic joint.

The Omnitrack™ movement solution (Fig. 1a) also had its functioning position changed by $180^\circ$. The ball guide, pos. 1 in Fig. 1(c), has been manufactured out of AmAlOx ceramic alumina in order to improve its seizure resistance. AmAlOx87 alumina (Astro Met Aluminum Oxide) comes from Astro Met, Inc., Cincinnati, OH, USA it’s a high purity.
99.8% aluminum oxide (alumina) ceramic which has been originally developed for critical load bearing medical implants, and optimized for maximum wear and corrosion resistance. A high density, diamond like hardness, fine grain structure and superior mechanical strength are its unique properties that make the AmAlOx alumina the appropriate material for demanding applications. The typical properties of AmAlOx87 alumina include a bulk density of 3.97 g/cm³, flexural strength of 482 MPa, Vickers Hardness of 2000 and a grain size of 2 microns. AmAlOx87 alumina has an unusually small grain size for an alumina ceramic and this enables extremely tight tolerances and surface finishes of 2 microinches Ra to be achieved.

These joints have been first tested in laboratory on the same tester (Fig. 2) and under the same conditions (only with flexion - extension movement and with constant load) [36] as the previous version with the balls in self-directed motion (SDBJ), which has been abandoned. Fig. 2(a) shows an overall view of this device.

![Figure 2](image.png)

**Figure 2** Device (a) and kinematic diagram of the testing device (b): 1 - electromotor; 2 - trapezoidal belts; 3 - recurrent reducing gear; 4 - wheel driving chain; 5 - gear box; 6 - gear reducer recurrent (periodic); 7 - universal joint; 8 and 10 - femoral heads; 9 – acetabular double piece; 11 - shaft; 12 - coupling with wedge and pull spline; 13 - cam; 14 - shaft; 15 - driven sprocket; 16 - Gall’s chain [36]

Monitoring of friction coefficient of hip prosthesis with the balls in self-directed motion (SDBJ) was compared to a classic metal on polyethylene prosthesis in anatomical position on an experimental test rig [36] showed in Fig. 3 (b), that shows the kinematic diagram of this device.

![Figure 3](image.png)

**Figure 3** (a) Variation of the flexion – extension over two gait cycles and (b) variation of the ratio \( R / BW \) during a normal gait cycle.

The device was built in such a way that the acetabular double piece is supported by only the two femoral heads that oscillate in two directions, similar to a hip. You can also see that the acetabular double piece moves at the same time as the femoral heads due to friction (item 8 and 10). The main features of this device are: simultaneous / alternative measurements of the friction coefficient; perfect timing in the kinematic and dynamic simulation of the hip joint; compliance with the angle formed by the load axis and the oscillation axis. The measured friction torque is a projection of the real torque, the latter resulting from the calculations. A cam - till - helicoidal compression spring (item 12) accomplishes the specific load to the hip articulation.

The cam (item 13) was synthesized according to the loading diagram. The cam was rocked in the rotation of the chain - Fig. 2 (b) items 4, 15, 16, and a shaft (item 14). The flexion-extension movement was described by a quadrilateral gearing (item. 5), which has turned the chain wheel rotation (item. 4) into an oscillation. Oscillation has been transmitted to the femoral head by means of a chain with bolts, with the ratio of 1:1 (Fig. 2, item 5) and a cardanic universal coupling.
For each gait cycle determinations of the friction coefficient were made for the self-directed balls joint (SDBJ) – Fig. 4 and the modified Omnitrack movement solution – MOMJ - Fig. 5.

**Figure 4** Comparison between friction coefficient and the angular speed modulus, in case of acetabular - femoral joint with self-directed balls (SDBJ). It is to be noted the reverse dependency between friction coefficient and load and direct dependency with the angular velocity.

\[ \mu(t); \ - \ - \ - N(t) / 10000 [N]; \ - \ - \ - \omega(t) / 25 [\text{rad/s}] \]

**Figure 5** Comparison between friction coefficient and the angular speed modulus, in case of modified Omnitrack movement acetabular - femoral joint - MOMJ joint in Fig. 1(b). It is to be noted the reverse dependency between friction coefficient and load and direct dependency with the angular velocity.

\[ \mu(t); \ - \ - \ - N(t) / 10000 [N]; \ - \ - \ - \omega(t) / 25 [\text{rad/s}] \]
With all the encouraging preliminary findings over MOMJ prosthesis behavior, their validation was required using an approved system of dynamic multiaxial testing. For this purpose we use a dynamic testing machine MTS Bionix (Fig. 6), equipped with a system for hip implants testing.

MoMJ testing was made in comparison with the testing of a classical prosthesis metal on polyethylene MoP (CoCr - UHMWPE). MTS Bionix system for implants testing is equipped with three rotating motors for movement of the internal-external rotation; for flexion-extension movement and for movement of abduction-adduction and with three displacement transducers, one for the movement of abduction-adduction, an angular displacement transducer for flexion-extension movement and an angular displacement transducer for internal-external rotation movement. In addition, MTS Bionix system has a transducer for the moment of torsion, with two Wheatstone decks, one for measuring linear force and the other to measure the torsion moment. The moment transducer is of resistive type and it is coupled with a current converter type 662 20 h-04, to processing received signals from each deck Wheatstone.

The test machine allowed setting number of cycles, the amount of the normal force on the joint implant (the force $F$ that has a pulsating form), the lower and upper limits of the angular displacement of each rotation, as well as the law of motion for each type of rotation according to ISO 14242-3.

Lubricant used was BSF (Simulated Body Fluid) with the 1,183 kg/m$^3$ density and viscosity of 0.84 Pa (HyClone, SH 30212.03).

Appropriate fitting of the sample was verified before the time of the test. It has been adjusted at the pump pressure value of 210 bar, the controller and the application "Station Manager" were started, by which they were made relations to the system calibration settings and adjusted. After that, zero settings had been done. After the command-response adjustments, have zeroed the output values for each axis (axial, torsion, flexion / extension, abduction / adduction, internal / external rotation). The support for testing of modular femoral heads is presented in Fig. 7.
Through the "ELITE" software the vertical push force and the displacement angles were set: flexion-extension, abduction-adduction, internal-external rotation, according to ISO 14242 upgraded in 2014, which sets the parameters for orthopedic implants testing.

Values in Table 1 show the force, were it can be seen that the maximum amount of force is 3 kN. The sign is negative because it is a compression force (the negative sense of the $z$ axis).

<table>
<thead>
<tr>
<th>Time (sec.)</th>
<th>Segments count</th>
<th>Wave</th>
<th>1 Limit (kN)</th>
<th>2 Limit (kN)</th>
</tr>
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<tbody>
<tr>
<td>0.0005</td>
<td>10000</td>
<td>Sinus</td>
<td>-0.3000</td>
<td>-3.0000</td>
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<tr>
<td>0.1195</td>
<td>10000</td>
<td>Sinus</td>
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<td>-1.5000</td>
</tr>
<tr>
<td>0.2000</td>
<td>10000</td>
<td>Sinus</td>
<td>-1.5000</td>
<td>-3.0000</td>
</tr>
<tr>
<td>0.1800</td>
<td>10000</td>
<td>Sinus</td>
<td>-3.0000</td>
<td>-0.3000</td>
</tr>
<tr>
<td>0.1200</td>
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<td>Sinus</td>
<td>-0.3000</td>
<td>-0.3000</td>
</tr>
<tr>
<td>0.3800</td>
<td>10000</td>
<td>Sinus</td>
<td>-0.3000</td>
<td>-0.3000</td>
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For abduction-adduction, internal-external rotation and flexion-extension angles were introduced the values in Tables 2, 3 and 4.

<table>
<thead>
<tr>
<th>Time (sec.)</th>
<th>Segments count</th>
<th>Wave</th>
<th>1 Limit ($)</th>
<th>2 Limit ($)</th>
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<tr>
<td>0.0005</td>
<td>10000</td>
<td>Sinus</td>
<td>3.0000</td>
<td>7.0000</td>
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<tr>
<td>0.1195</td>
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<td>Sinus</td>
<td>7.0000</td>
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<td>-4.0000</td>
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<tr>
<td>0.3800</td>
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<td>Sinus</td>
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<th>1 Limit ($)</th>
<th>2 Limit ($)</th>
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<td>Sinus</td>
<td>-10.0000</td>
<td>2.0000</td>
</tr>
<tr>
<td>0.5000</td>
<td>10000</td>
<td>Sinus</td>
<td>2.0000</td>
<td>-10.0000</td>
</tr>
<tr>
<td>0.4995</td>
<td>10000</td>
<td>Sinus</td>
<td>-10.0000</td>
<td>-10.0000</td>
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</tbody>
</table>

<table>
<thead>
<tr>
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<th>1 Limit ($)</th>
<th>2 Limit ($)</th>
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<td>1.0000</td>
<td>Sinus</td>
<td>25.0000</td>
<td>-18.0000</td>
</tr>
<tr>
<td>0.5000</td>
<td>1.0000</td>
<td>Sinus</td>
<td>-18.0000</td>
<td>25.0000</td>
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<tr>
<td>0.4995</td>
<td>1.0000</td>
<td>Sinus</td>
<td>25.0000</td>
<td>25.0000</td>
</tr>
</tbody>
</table>

The values presented in tables 1-4 are ranked according to the angular values set by software “ELITE”, of the limits 1 and 2.

After entering values for force and angle of movement in flexion-extension, abduction-adduction, internal-external rotation, it was set the number of test cycles to 50000 cycles. To test the MOMJ joint it was considered the fact that a human subject’s movement of flexion-extension in one second (1s), is one cycle per second.

3. RESULTS AND DISCUSSION

The prototype was subjected to simultaneous requests of flexion-extension, abduction-adduction and internal-external rotation during a cycle and was considered a time of 5 seconds, where human subject achieves complete 5 cycles. Variation law of force and angles was established according to ISO 14242. In Fig. 8 is shown the graph of vertical contact force: the answer came from the force transducer is represented by the red color and blue is the command set. The presentation is done in comparison, for the conventional MoP CoCr/UHMWPE in sliding friction, and for new MoM joint with rolling friction, generic called MOMJ.
Figure 8 Time graph of the contact force, command-response (blue-red) when testing the MOMJ (a) and (b) the testing of a conventional MoP implant

Time graph of the in time contact force of the vertical and angular displacement (Fig. 9) flexion/extension, is presented at the MOMJ joint testing (a) and (b) when testing the conventional MoP implant.

Figure 9 In time graph of the contact vertical force and angular displacement of the flexion/extension (a) when testing the prototype MOMJ and (b) when testing the implant conventional MoP
At the same time, the graph of the vertical contact force and angular displacement of the abduction/adduction (Fig. 10) is presented when testing the MOMJ prototype (a) and (b) when testing the implant conventional MoP.

![Graph of vertical contact force and angular displacement](image1)

**Figure 10** In time graph of the contact vertical force and angular displacement to abduction/adduction (a) when testing the prototype MOMJ, (b) in conventional implant test.

In Fig. 11 is presented the graph of normal force and angular displacement in internal rotation/external rotation (a) when testing the prototype MOMJ and (b) of the conventional implant.

![Graph of normal force and angular displacement](image2)

**Figure 11** In time graph of the vertical contact force and angular movement of the internal/external rotation (a) when testing the prototype MOMJ and (b) to conventional implant testing.
It can be seen as a function of time graph of the contact vertical force and angular displacement command-response (blue-red) when testing the MOMJ (a) and the testing of a conventional implant MoP (b) is very similar for both abduction/adduction (purple-red), flexion/extension (blue-dark blue), internal / external rotation (yellow-green).

Representations in Figs 12 and 13 are very important because they are actually validating the principle of the prosthesis with rolling friction.

In Fig. 12 is presented the graph of the vertical contact force (blue) and of the moment of friction (in red), for the testing of the prototype MOMJ.

![Graph](image)

**Figure 12** In time graph of vertical contact force (blue) and of the friction moment (in red), at the MOMJ joint testing

Fig. 13 shows the graph of a function of the vertical contact force (blue) and of the moment of friction (in red), in the testing of conventional MoP hip joint implant.

In these graphs, the minimum and maximum values of the variation of the magnitudes represented can be observed. These values are marked on the x axis with A and B points.
The joint of the hip implant MOMJ presented in Figs 1 (b) and (c) is a spherical joint with 3 degrees of freedom, which represents the three rotations around the coordinate axes ($\omega_x$, $\omega_y$, $\omega_z$). Therefore, this couple limits the 3 degrees of freedom, i.e., the translations on 3 axes.

Translational constraints on the 3 coordinate axes are materializing by forces $W_x$, $W_y$, $W_z$ - Fig. 1 (d). The friction moment in a spherical joint is given by the relationship:

$$M_f = \mu \cdot R \cdot W,$$

where
- $M_f$ is torsional moment of friction,
- $\mu$ is friction coefficient,
- $R$ is the joint radius (in the case of the femoral head of 28 mm, $R = 14$ mm = 0.014 m)
- $W$ is the resultant of forces $W_x$, $W_y$, $W_z$ from joint (mean the normal contact force on the joint), whose values have been set to 0.3 kN minimum value and 3 kN maximum value.

In the MOMJ joint case, $M_f$ is torsional friction torque of all frictions, recorded between the femoral head, balls, and acetabular cup.
On the basis of the presented charts, Tables 5 and 6 summarize the values of moment of friction recorded and of the calculated global friction coefficient in testing of the prototype MOMJ, compared to conventional MoP implant testing.

Table 5: Values of the flexion - extension (FE) angle for prototype MOMJ, according to ISO 14242

<table>
<thead>
<tr>
<th>Graph</th>
<th>Point</th>
<th>W [kN]</th>
<th>M [kNmm]</th>
<th>µ</th>
</tr>
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<tbody>
<tr>
<td>Fig. 12 (a)</td>
<td>A</td>
<td>0.3</td>
<td>0.1</td>
<td>0.0238</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>3</td>
<td>0.3</td>
<td>0.0072</td>
</tr>
<tr>
<td>Fig. 12 (b)</td>
<td>A</td>
<td>0.3</td>
<td>0.05</td>
<td>0.0119</td>
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<tr>
<td></td>
<td>B</td>
<td>3</td>
<td>0.6</td>
<td>0.0143</td>
</tr>
<tr>
<td>The average value of the global friction coefficient</td>
<td></td>
<td></td>
<td></td>
<td>0.0143</td>
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</table>

Table 6: Values of the flexion - extension (FE) angle for conventional implant MoP, according to ISO 14242

<table>
<thead>
<tr>
<th>Graph</th>
<th>Point</th>
<th>W [kN]</th>
<th>M [kNmm]</th>
<th>µ</th>
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</thead>
<tbody>
<tr>
<td>Fig. 13 (a)</td>
<td>A</td>
<td>0.3</td>
<td>0.1</td>
<td>0.0238</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>3</td>
<td>0.7</td>
<td>0.0167</td>
</tr>
<tr>
<td>Fig. 13 (b)</td>
<td>A</td>
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<td>0.1</td>
<td>0.0238</td>
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<td></td>
<td>B</td>
<td>3</td>
<td>0.5</td>
<td>0.0119</td>
</tr>
<tr>
<td>The average value of the global friction coefficient</td>
<td></td>
<td></td>
<td></td>
<td>0.0190</td>
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</table>

It appears that when testing MOMJ joint, the medium value of global friction coefficient (µ = 0.0143) is less than in the conventional MoP implant (µ = 0.0190), which is particularly gratifying.

4. CONCLUSIONS

The studies presented in this paper are the result of over 15 years of research and have involved many complementary investigations such as those relating to the seizure and lubrication, materials and their surface condition, manufacturing technologies, and last but not least the calculation values of the efforts and determination of the mechanical mode of transmitting them between acetabular cup, the balls and the femoral head. Research has been difficult, as the goal of the establishment of a total hip prosthesis with rolling friction.

In this study researchers found that total hip prosthesis with rolling friction made based on an Omnitrack solutions with low friction movement is a viable proposal, howeer it has some limitations.

The materials used (SS316L) were not the latest generation (CoCr or Ti6Al4V), although they had similar mechanical properties. Also, there were no tests done specifically for wear. The only findings were made on the wear at the end of the tests of friction (50000 cycles), macroscopic and microscopic inspection of the femoral head, acetabular cup and balls. They have not shown evidence of any scratch made of wear debris, rolling balls traces on the femoral head and acetabular cup or seizure scars of the bolls on the femoral head or acetabular cup. Also were not observed roundness deviations of the balls.

Researchers face a surprising tribologic validation because the real contact area between the femoral head and acetabular cup that hols uploading should be higher in the case of classical MoP, at least theoretically. In the case of the proposed new joints MOMJ loading is transmitted through 106 balls with a 2.5 mm diameter.

The research has so far lead to the requirement of further studies to elucidate this aspect. Future studies must also be focused on the wear surfaces inherent to this joint, in the same conditions of movement and loading, as well as on the its character, and evaluation of wear amount depending on the principal factors of influence (material, load, relative speed). This involves finding a method for quantitative evaluation of precision value of wear.

References


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