Considerations upon applying tripodic coupling in artificial hip joint

S Alaci¹, M C Ciornei², C Filote¹, F C Ciornei¹ and M C Gradinariu¹
¹ „Stefan cel Mare” University of Suceava, Romania
² The University of Medicine and Pharmacy „Carol Davila”, Bucharest, Romania
E-mail: alaci@fim.usv.ro

Abstract. The employment of tripodic joint allows creation of homokinetical transmissions and thus it is expected that at the use of such a transmission for a dynamical system with smooth enough inputs, the outputs should maintain the same characteristics. The present paper presents a comparison between the effect of using a spherical joint in spatial mechanisms – the classical solution for hip joint implant, and the effect of replacing such prosthesis with a tripodic coupling.

1. Introduction
The most frequent diseases concerning the skeletal system are met in joints, [1], [2], [3]. The causes of the diseases are multiple. A first category of causes consists in the accidents occurring in domestic life. In the case of accidents, the main characteristic is the sudden variation of kinematical characteristic parameters of the system leading to the development of reaction forces and torques of appreciable values and therefore, the skeletal system can be assimilated as a system with percussion. These situations are met in sports medicine and vehicle accidents.

The effect of applying sudden restraints to the elements - bones of the skeletal system is difficult to anticipate, and local damages in the vicinity of contact zones between bones can occur or even fractures at remote regions with respect to the zone where the forces are applied.

A second type of damages occurs as a result of tribological phenomena characteristic to joints. There can be reminded the nonconformity of the boundary surfaces of the regions which enter in direct contact, between these surfaces occurring concentrated contacts where the contact pressures attain significant values, the presence and characteristics of sinovial liquid or rather its absence, the degree of wear of boundary cartilages, the mechanical characteristics of the bone substrate etc.

Destroying the contact zones of joints has significant effects upon everyday life: pains, seldom unbearable, the impossibility of displacement when the locomotion system elements are affected, impossibility of mastication when the temporomandibular joint is affected [4], [5] or the limitation of managing current tasks when the upper limbs are involved.

When the contact region from joints is affected in an early stage, the damages are remediated via drug treatment. Unfortunately, in numerous cases the stage of the disease requires surgery and joint replacement. The hip joint is an example of the most affected joints of the skeletal system, [1], [2].

2. The hip joint prosthesis
The hip joint, a highly stressed joint of the skeletal system, is presented in figure 1. The first surgery of hip replacement was performed by Gluck, [6], in 1891 in Germany. He used an ivory sphere to replace
the femoral head and nickel-plated screws for attaching it. Since then, the method evolved and especially the materials used for the femoral head and acetabular cup and the methodology of attaching these elements to the corresponding bones, figure 2.

From structural point of view, all replacing solutions suppose using a spherical joint. The spherical joint presents the advantage of constructive plainness. The main disadvantage of applying this replacement solution consists in the fact that, if one considers fixed one of the elements of the pair, the points of the mobile element will describe spatial curves positioned on concentrically spherical surfaces, \( \Sigma_{\text{sph}} \) with the centre in the centre of the pairs, figure 3.

The present paper analyses a solution of total replacement of the hip joint with a tripodic pair, figure 4. The tripodic joint is characterised by the presence of three pairs of type class 1 between the two elements. Considering the manner in which higher pairs are obtained, two constructive solutions for tripodic joint are possible: straight line-straight line contact, [8], [9], [10], [11] and point-plane contact, [12].

In figure 4 there is presented the tripodic joint with point-plane type contact. As constructive solution, achieving the joint from figure 4 assumes obeying the condition that three points from one of the elements should be permanently in contact with three planes that are respectively placed on the second element. Likewise the spherical joint, when one of the elements is considered fixed, the other element has three degrees of freedom. Different from the spherical joint, when all three motions are rotations, in the case of tripodic joint, the degrees of freedom depend on the other joints in which the mobile element is involved.

Mariot and K'nevez, [9], consider the case when a mobile element simultaneously takes part to a tripodic joint and to a spherical joint. In [13] it is considered a mobile element creating a tripodic joint of point-plane type and a planar pair, and it is shown that when the three planes have a common line and are equidistant and the points belong to a circle positioned in a plane parallel to the plane of planar pair, the transmission become homokinetical.

In figure 4(a) is presented the manner of building a tripodic coupling of plane-point type. The three point-plane contacts are obtained by introducing three spheres, attached to one of the elements, in three channels, with the width equal to spheres diameter, made in the second element.
In figure 5 it was considered a random surface ($\Sigma$) attached to the mobile element. In this form, a drawback of the transmission is given by the sphere-channel wall contacts, where the contact pressures have important values. To avoid this drawback, the first class pair is replaced by an assembly of two pairs, planar and spherical, as shown in figure 6.

Considering that the mobile element of spherical pair is constrained to create a second spherical pair, the part will have a motion of passive rotation around the axis passing through the centres of the two pairs and thus it could not be capable of transmitting a torque parallel to the line passing through the centres of spherical joints.

**Figure 3.** Spherical joint.  
**Figure 4.** Tripodic pair: a) point-plane contact; b) straight line-straight line contact.

**Figure 5.** Relative motion from tripodic joint.  
**Figure 6.** Solution for attenuation of contact pressure.
3. Comparison between the effect of employment of a spherical joint and a tripodic coupling in a spatial mechanism

The kinematical effects of the use of spherical joint and tripodic coupling are presented subsequently. Using the DMU-Kinematics module of CATIA DASSAULT Software, the two mechanisms were cinematically simulated. As shown in figure 7, the two mechanisms have the same ground and the same crank. Using DMU-Kinematics module for kinematical simulation of a mechanism requires, for set values of the position parameters of driving elements, all positions for the other elements should be well stated. In figure 7 one can notice the structural changes made with the aim of fulfilling this condition. Thus, for the initial RSSP mechanism, the existence of two spherical pairs should lead to a motion of passive rotation around the axis passing through the centers of the two pairs. To eliminate this passive degree of freedom, two revolute pairs are introduced, having normal axes and therefore the mechanism becomes a RSRRP one. By introducing a last pair where a rotation and a translation about the same axis are allowed (cylindrical pair), the final form of the mechanism becomes RSRC. For the mechanism containing in its structure the tripodic pair, the intermediate element was constrained, thus the centre of tripodic joint (the centre of the sphere from which the tripodic arms start) must permanently remain fixed. The final element makes with the ground a prismatic pair.

Figure 7. Mechanisms with spherical joint and tripodic joint.

Figure 8 presents the comparison between the velocities of the last elements of the two mechanisms. It is obvious that by replacing the spherical pair with the tripodic one, the law of motion of the final element is not modified.

It must be mentioned that the condition that the length of intermediate element should be the same for both mechanisms was obeyed. Hence, the distance from the centre of tripodic joint $Tr1$ to the centre of spherical joint $S_1$ is the same with the distance from the centre of spherical joint $S_2$ to the axis...
of revolute pair $R_2$. Figure 9 presents a comparison between the variations of angular velocities of coupling elements (femoral shaft) from the two mechanisms. The differences between extreme values of angular velocity of the last element from both mechanisms are huge and the software cannot plot the graphs at the same scale, consequently, the plot scales for the two curves differ. The one presenting a sudden tip corresponds to the case of classical prosthesis, with spherical joint. In the case of tripodic joint there is a smooth motion, the rotation velocity varying in the range $[5.7 \div 62.5] \text{ rot/min}$, opposite to the case of classical joint, where the curve presents a peak, a maximum in the range $[17.9 \div 2460] \text{ rot/min}$. The variation of angular velocity in a wide domain during a short period will lead to incidence of appreciable angular accelerations and implicitly, to forces and moments of inertia with particular damaging effects upon the hip joint.
4. Conclusions

The paper presents a solution for total hip joint replacement with a less common joint, the tripodic joint. After a brief review of main tripodic joints and their properties, a comparison between kinematics behaviours of the two mechanisms is presented; these mechanisms have the same dimensional characteristics, a common driving element but structurally differing by the fact that a spherical pair from one mechanism was replaced by a tripodic pair.

Using a specialised software for kinematical analysis, it is emphasised the fact that the effect of replacing the spherical joint by the tripodic pair is an unchanged motion of the last element.

By contrast, the coupling elements entering the spherical pair and tripodic pair respectively, present absolutely different dynamic behaviour. While in the replacing mechanism the coupling element has a quasi-uniform rotation motion, in the initial mechanism, the same element is subjected to appreciable stresses due to sudden variation of the element’s angular velocity.

5. References

[1] Maquet P G J 1985 Biomechanics of the Hip As Applied to Osteoarthritis and Related Conditions (Springer)
[2] Pauwels F 1976 Biomechanics of the Normal and Diseased Hip Theoretical Foundation, Technique and Results of Treatment An Atlas( Springer)
[3] Imura S, Akamatsu N, Azuma H, Sawai K and Tanaka S 1993 Hip Biomechanics (Springer)
[4] Hannam A G, Stavness I, Lloyd J E and Fels S 2008 A dynamic model of jaw and hyoid biomechanics during chewing Journal of Biomechanics 41 pp 1069-1076
[5] Koolstra J H 2002 Dynamics of the human masticatory system Critical Review in Oral Biology & Medicine 13 pp 366-376
[6] Knight S R, Aujla R, Biswas S P 2011 Total Hip Arthroplasty - over 100 years of operative history Orthopedic Reviews 3(2)
[7] http://www.saburchill.com/chapters/chap0008.html, accessed April 2016 Ball and Socket Joints
[8] Akbil E and Lee T W 1984 On the motion characteristics of tripode joints. Part 1: General case, Part 2: Applications ASME Journal of Mechanisms, Transmissions, and Automation in Design 106 pp 228-241
[9] Mariot J P and K’nevez J-Y 1999 Kinematics of tripode transmissions. A new approach Multibody system dynamics 3 pp 85-105
[10] Wang X F, Chang D G and Wang J Z 2009 Kinematic investigation of tripod sliding universal joints based on coordinate transformation Multibody Systems Dynamics 22 pp 97-113
[11] Urbinati F and Pennestri E 1998 Kinematic and Dynamic Analyses of the Tripode Joint Multibody System Dynamics 2 pp 355-367
[12] Phillips J 1984 Freedom in Machinery vol. 1 (Cambridge University Press)
[13] Alaci S, Ciompi F C and Filote C 2013 Considerations upon a new tripod joint solution Mechanika 19(5) pp 567-574
[14] Zamani N G and Weaver J 2012 CATIA V5 Tutorials Mechanism Design & Animation Release 21 (SDC Publications)

Acknowledgments

The authors acknowledge financial support from the project “Integrated Center for research, development and innovation in Advanced Materials, Nanotechnologies, and Distributed Systems for fabrication and control”, Contract No. 671/09.04.2015, Sectoral Operational Program for Increase of the Economic Competitiveness co-funded from the European Regional Development Fund.