Numerical and experimental analysis of a personalized prosthesis for a patient with unilateral hip osteoarthritis

Juan Alfonso Beltrán-Fernández[1a], Omar Rolando Ruiz-Muñoz[1b], Luis Héctor Hernández-Gómez[1c], Itzel Bantle-Chávez[1d], Carolina Alvarado-Moreno[1e], Alejandro González-Rebattú y González[2f], Edgar Alfonso Figueroa-Rodríguez[1g], Adolfo López Lievano[1h], Pablo Moreno-Garibaldi[1i], Nefi Pava-Chipol[1j] ,

1. INSTITUTO POLITÉCNICO NACIONAL - Escuela Superior de Ingeniería Mecánica y Eléctrica - Sección de Estudios de Posgrado e Investigación Edificio 5. 2do Piso, Unidad Profesional Adolfo López Mateos “Zacatenco” Col. Lindavista, C.P. 07738, Ciudad de México, México.

2.-Hospital Regional 1 De Octubre – ISSSTE - Av. Instituto Politécnico Nacional #1669, Lindavista, 07300, Gustavo A. Madero, CDMX.

[a]jbeltranf@hotmail.com, [b]omarrolandocv@hotmail.com, [c]luishector56@hotmail.com, [d]itzi.bantle@gmail.com, [e]aly-oroshiwa@hotmail.com, [f]alexrebat-tu@hotmail.com, [g]efigueroa2528@gmail.com, [h]k_lievano@hotmail.com, [i]pmg170588@gmail.com, [j]sowbran@gmail.com

Abstract
In this work, the design and numerical evaluation of a personalized hip prosthesis for a 31 year old male patient, who suffered of unilateral coxarthrosis (osteoarthritis of the hip joint), was performed. The development of the study started with the data acquisition of the patient´s computed axial tomography and was based on engineering techniques such as, computerized digitalization of the physical model through a highly specialized Scanner, trademark ANSYS and the creation of the final model as a computerized archive, whose design can be adapted to the patient´s needs with the usage of the specialized 3D design platform Solidworks.
First, the development of an anatomical accurate implant is conducted with the acquisition of the patient´s anthropometric data and also with the employment of a numerical analysis following the finite element mathematical method. This, in order to evaluate the posture of the patient, making use of his total weight when he is standing on one leg. Furthermore, the structural mechanical evaluation of the prostheses was set under evaluation, considering the osseous integration of the femoral bone and the acetabulum before and after surgery.

Keywords:
Image correlation, tomography, ANSYS, prostheses, unilateral hip osteoarthritis

Although the main cause of the hip osteoarthritis is unknown, the best way to define this particular disease is taking into account the whole clinical picture that includes a group of heterogenic pathologies with common clinical manifestations. For instance, the disease is characterized by the alteration between the formation and degradation cycle of the joint cartilage and the subcondral bone, causing morphological lesion areas that provoke pain and incapacity. This pathology affects 20-30 percent of the Mexican population and is common in patients between 50-55 years old.
Considering the fact that the hip is one of the principal components of bipedal mammals for the balance and the support of the body, the coxarthrosis can be defined as one of the most disabling pathologies in its category. Due to its insidious start, the patient isn´t initially aware of the beginning of the pain, the intensity also, is variable and is accompanied with joint rigidity each time a movement begins. The disease is the direct consequence of a constant usage of the joint when walking. The pain, however, has a tendency to vanish when the patient rests. Other particular symptoms are the movement limitation and the functional impotence in form of a progressive limp that can culminate in difficulties when the patient sits down or gets up of a chair, crosses the legs when putting the shoes on or presents painful difficulties when trying to bend or sitting astride in order to pick up an object of the floor.

According to Rozadilla et al. (2002), “this disorder can be classified as unilateral and bilateral. Patients who suffer of unilateral coxarthrosis present previous articular lesions in the affected area, forcing the osseous system to compensate and balance the total patient´s weight on one side, having as consequence, a tendency to develop similar lesions in the opposite hip joint over the years”. [1]

Due to the evolution of the design for whole joint prostheses, there is a constant increment of the need to enhance the role of the biomechanical nature of the body´s joints. The mechanical problems associated to a total replacement of the joint include aspects that concern load surfaces, mechanical failures, detachments and dislocations of the implant over the joint´s surface. Having as goal the obtention of this information, multiple experiments in vitro have been conducted using joints and tissues that belong to human corpses, simulating natural movements and loads to which the joints are usually submitted. These experiments were also complemented with studies of human locomotion that were performed in vivo. [2]

In this study, the clinical case of a 31 year old patient who suffers of an advanced case of degeneration in the right pelvic area, particularly the zone of the acetabulum and the femoral head was analyzed. The male patient weights 48 kg and is 1,64 m high.

“The digital technology has provided the necessary computational capacity to create a wide range of biomechanical models”, Chaffon (1969). This is the reason why the design of the prostheses was carried out employing the ScanIP software, which allowed designing an accurate model of the patient´s clinical characteristics as shown in Figure 1.

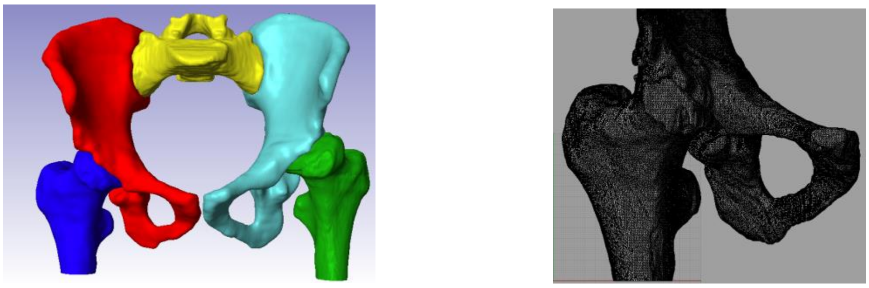

Fig. 1.Tridimensional representation of the patient´s right and left hip after rendering.

Based on the tridimensional model, specialists analyzed the right side of the pelvic system where the damage was located. According to the Wolff´s Law, the natural mechanical loads which are applied over the osseous surface have a great impact on the development of the bone tissue. [3]
The condition of the surfaces showed a significant depletion that culminated in disabling pain.

After exporting the tridimensional model´s data in form of a .stl archive to the Rhinoceros platform, 4.0, the number of elements which compose the model´s surface was reduced in order to enhance the manipulation and design of the final archive with the usage of other types of software. Subsequently, the archive was converted into an .iges file and modified through the software Solidworks ®.

The first step in designing the personalized hip prosthesis ‘system consisted of creating a device that needed to be adjusted to the acetabulum´s body, which was designed according to the surgeon´s indications through the usage of a Burch-Shnider´s® reconstruction ring (Zimmer), as shown in Figure 2.

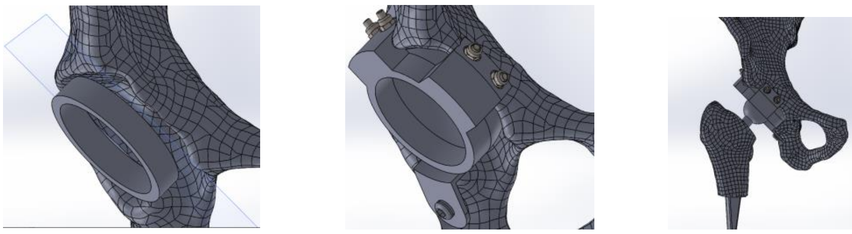

Fig. 2. Burch-Shnider´s® reconstruction ring (Zimmer), Ruíz Muñoz (2016).

Having as objective the replacement of the rotation´s center, the acetabulum´s spare part was adjusted to the right hip´s bone surface. Areas that presented central and oval cavitary defects of different sizes (type IIb Paprosky) lesions were reconstructed through the implementation of a Trabecular Metalic Technology System, known as ® TMT (Zimmer) with a high coefficient of friction that ensures a primary stability and presents a good osteointegration and a low tendency to be reabsorbed by the body. Unfortunately, some disadvantages are the fact that a long term positive result is not guaranteed and also the behavior of the metal-metal interface in cases of advanced infection has not been fully studied, to mention a few. [4]

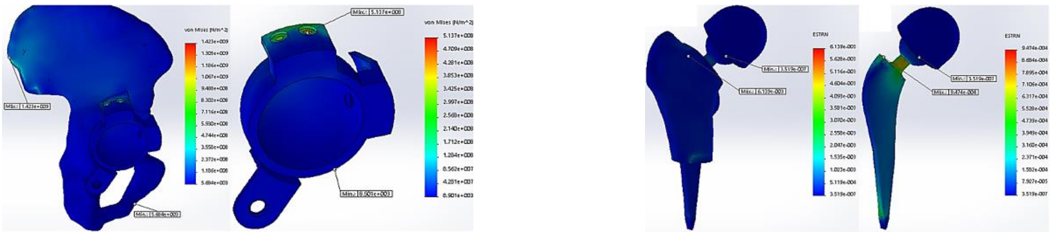

Fig.3. Numeric Results.

Conclusions

Based on the numerical performed analysis, the distribution of the loads in the areas near the implants of the femur and the pelvis manifested a significant reduction of the charges provoked by the natural loads of the body in each one of the cases of study. Additionally, the micro displacements obtained during the numerical simulations, considering the projection of the primary and secondary stabilization during the patient's march with and without the help of a stick, were analyzed. The specialists obtained a result of 3.185 μm displacement for the stem and 3.482 μm for the reconstruction system when the patient made use of a stick in order to walk. In comparison, the values which were obtained for both components when the patient walked without a stick were of 21.56 μm and 18.31 μm, respectively.

In conclusion, the lesions caused by mechanical loads on the hip´s surface provoke a deformation of the joints, which adapt a new size, form and structure. The femoral head presented in this case a pathological structural change that culminated in disabling pain. The new system was therefore, adapted to these structural changes and distributed the natural loads of the patient when walking, creating a resistant and personalized structure.

References

[1] Rozadilla, A., Mateo, L. & Romera M., *Hip arthrosis, The medicine today*, Vol. 62 (2002), p. 31-37.
[2] Nordin, M., Frankel, V.H., *Basic Biomechanics of the Musculoskeletal Body*, edited by McGRAW HILL – INTERAMERICANA, (2004),
[3] Cowin, S., Bone Mechanics Handbook, edited by CRC Press, (2001).
[4] Hasart, O., Perka, C., Lehnigk, R., Thotz, S. , *Reconstruction of great acetabular defects with metalic increase. Trabecular metallic technology*. Tec. Quir. Otop. Traumatol., Vol. 20, (2011), p. 228-238.