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NUMERIC-EXPERIMENTAL ANALYSIS OF STRESS IN AN INNER FIXER FOR HUMAN VERTEBRAE

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Abstract. This paper presents a Study Numeric-Experimental to analyze stresses in order to know the State of the field stresses in the Inner Fixer for Vertebrae Human. The Inner Fixer was developed by the orthopedist Manuel Dufoo Olvera affiliated to "Servicio de Columna del Hospital General de la Villa", in the Mexico City. This study is made with the purpose of validating the numerical study of human Lumbar vertebrae subject to main physiological loads that suffers the human organism in this zone. Numerical analysis is done using the finite element method (FEM); two techniques are used to the experimental part: the Reflective Photoelasticity and the Electrical Extensometry. Reported in this paper is a study of Flexo-compresión as validation of human bone system. Use vertebrae pig as a viable alternative to the use of vertebrae human and because their mechanical properties are similar. The analysis includes four phases and intervertebral discs (with great complexity) are taken into account in one of them. The analysis consists of four phases or applications: 1. intact structure including the intervertebral discs. 2. Structure with the inner fixer, 3. Total Corpectomy and inner fixer, 4- Total Corpectomy, inner fixer, and anterior iliac crest Insert. Found in both analyses (numerical and experimental) behavior and the results are similar.

1 INTRODUCTION

The interest in the treatment of the thoracolumbar fractures has intensified in the last years, by an understanding of the abnormal anatomy in the area of the vertebral fractures obtained by the use of the computerized mielography, tomography and magnetic resonance (Reyes-Sánchez et al, 2004). The fixation of column with bars or plates as longitudinal members and pedicular screws has given good results in the treatment of several sufferings of the thoracolumbar column in the stabilization of fractures (Cunningham et al, 1993).

The application of the biomechanics principles for the handling of the fractures of long bones also has value for the handling of unstable traumatic injuries of the thoracic and lumbar column. Actually the principle does not work on each vertebral body, but rather, takes to the entire column like a bony linear construction, resembling it a long bone. This involve that the thoracic-lumbar treatment of the fractures and dislocations, are treaty with the same form that the femur fractures, tibia, bones of the thoracic extremity, apply corrective forces. Nevertheless, for effects of the stabilization with certain implants, is not due to consider to the column like a long bone, due that the spine has numerous short bones arranged one on another one and articulated, the fixation is due to make only on the unstable segment, making then "short segmental fusions". The spine surgeon will have to stabilize only the unstable site. The vertebral segments that are healthy man have the fusion through intervertebral bones, discs, ligaments, capsules you will articulate and muscles that are in charge to maintain their own stability physiological (Tamara-Montes et al, 2000). In general, the objective to model and to simulate muscle-skeletal elements system is to predict muscular forces, reactions in the joints and other parameters that are difficult or virtually impossible to measure (Zee et al, 2007). The mathematical Models of numerical type as it is the Finite Element Method (FEM) also can be used to find the answer structural to outer loads, nevertheless have one more a more important function in the establishment of the inner answers, such as the stresses and strains. An important step in the creation of the model of Finite Elements is to validate the results with experimental data obtained in experiments in vitro with parts of human corpse (Wheeldon et al, 2006). In this Investigation stress analysis appear practiced to a system of Internal Fixation for the treatment of vertebral bodies that have undergone fracture by burst. This type of fracture takes place when a person falls of foot of a greater height of 4 meters (Tejeda et al, 1998). The used technique is the one of corpectomy total (Tejeda et al, 1998), the most unfavorable case, is to say when L3 lack (lumbar vertebra 3) and the fixer device subjects to the bodies L2 and L4. The analyses are made using two types of vertebral models and a single fixer device. Which are: 1.- Two Nylacero discs act like vertebral bodies (Reyes-Sánchez et al, 2000). This model provides important information of the assembly of the connected System vertebra-fixer device. 2. - Pig vertebrae by the possibility are used of making experimental analysis taking in account intervertebral discs; 3. - Models of human vertebrae are analyzed. In order to carry out the study several models of three-dimensional Finite Elements are developed. For the first set of models, the experimental protocol for this type was transferred of you implant to the numerical scope. For the second, consisting of models two movable segments of the pig spine (lumbar region that includes altogether: L2-l3 and L3-l4) for third, are used the same conditions that the pig vertebrae, single that with human vertebrae.

It is necessary to remember that a movable segment include two vertebral bodies, and the common intervertebral disc to both (Nordin and Frankel, 1989). This analysis is for obtaining their behavior from the point of view of the stress analysis. Immediately, a model coupled- system bone-Implant, where implant act like a mechanical bridge to unload to the central adjacent vertebra to other two to which to set the implant: This phase of study contemplates, (1), the presence of Implant with the healthy Intermediate body and both intervertebral discs. (2) The case more unfavorable than is when there is no present Intermediate body (total Corpectomy) (3) appears a model similar to the previous one but with an inserted one of crest iliac that is placed surgically in the front of the human body. Later a Hybrid Experimental Analysis is made, in which it becomes use of extensometers and photoelasticity reflecting with the purpose of verifying the previous conditions. In the third set of models, bypassed human L2 and L4 with the fixer device are taken, of simple way (total corpectomy) and with the inserted one of crest iliac.

In order to obtain the previous thing, the tools of stress analysis are used focused to the design, considering that when biomechanical problems are approached (development of prosthesis and you implant in orthopedic) exists some factors that must be considered to obtain satisfactory results. In the first place the systems must be analyzed of integral form. This is, is not valid to model the inert parts only, such as prosthesis and implants. When a strange body within a live organism is inserted (especially when it is coupled to a bone) alters to the stresses pattern and resulting deformations of the application of physiological loads. Such changes bring with him a series of events that they cause that the bone increases or diminishes its density and consequently modifies its characteristics of resistance and rigidity.

2 MATERIALS AND METHODS

For the construction of the models of finite Elements, the following aspects were considered:

2.1 Geometry

With regard to the pig vertebrae, physical slices became (nontomographics) whose images were digitized by means of photography. Once it is counted on the geometry of all the involved elements, a geometric study was made (CAD) to integrate, in all the cases the model of implants to the models corresponding to each connected pair (Nylacero bodies and pig vertebral bodies), in agreement with the indications of a medical specialist surgeon in this type of surgery. The figures 1a, 1b and 1c show the three-dimensional models of these assemblies.

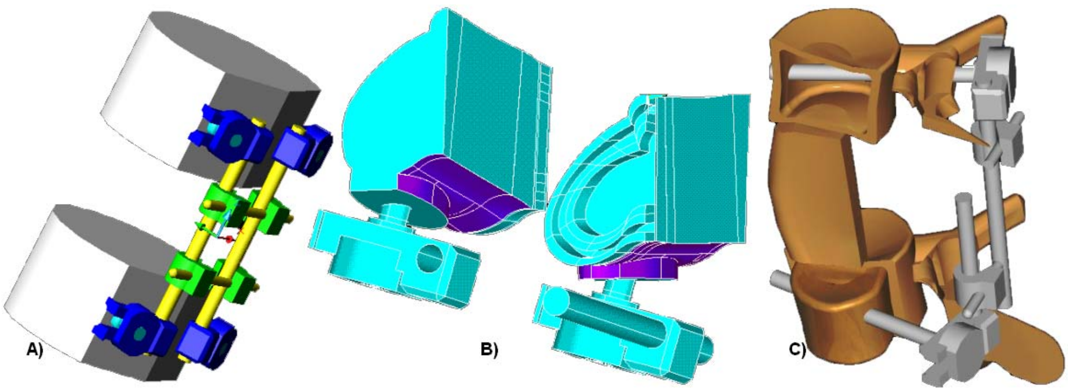

Figure 1 Fixer device mounted in a) Nylacero bodies, b) Pig Vertebrae and c) Human Vertebrae.

2.2 MATERIAL PROPERTIES

As far as the organic material, two main types of bony material, cortical bone and trabecular bone are considered. In addition, the parts of the intervertebral disc are considered such as, the terminal plates, the annular fibers and the pulpy nucleus: En whatever to the inert part, is to say the fixer device, is made with Titanium. The considered mechanical properties for all the materials are basically the Modulus of elasticity and the Poisson's ratio. The properties of these materials are in table 1, (Kasra et al, 1992; Wang, 1997).

Part of the Model:	Young modulus (MPa):	Poisson's ratio:
Cortical Bone	1200	0.29
Hueso Trabecular	100	0.29
Terminal plate	500	0.40
Terminal Disc	3.4 Directions to 30° and 150° in XZ	0.40
Pulpy Nucleus	3.4	0.49
Nylacero	2736.99	033
Fixer device	102000	0.30

Table 1 Vertebral body’s Material Properties.

2.3 Load and Border Conditions

As far as the conditions of load, are considered 4 different loads that represent each one of the types of load quasi -static which they are used to represent the types of load that is put under the human body (Reyes-Sánchez, 2004):

1. Flexo-compression (Compression that causes flexion. (Using a 50 kg load.)
2, Anterior lateral flexion (25 Nm (Rohlman, 1997).
3, Right and left torsion (25 Nm): and
4, Sum of all the previous ones (stress combined).

In the border conditions the same ones that are used in the protocols of experimentation for the fixer devices (Cunningham, 1993), in the models to compression are considered was only used half of the model and therefore conditions of symmetry were applied to the cut plane and in most of the models, also symmetry in the plane of cut of half of the longitudinal bars was considered, on the other hand, the rotation point was determined in which the moments act and to these points the movement is restricted to them in such a way that they only can move throughout z-axis (Damián, 2003). Is a schematic diagram in Figure 2.

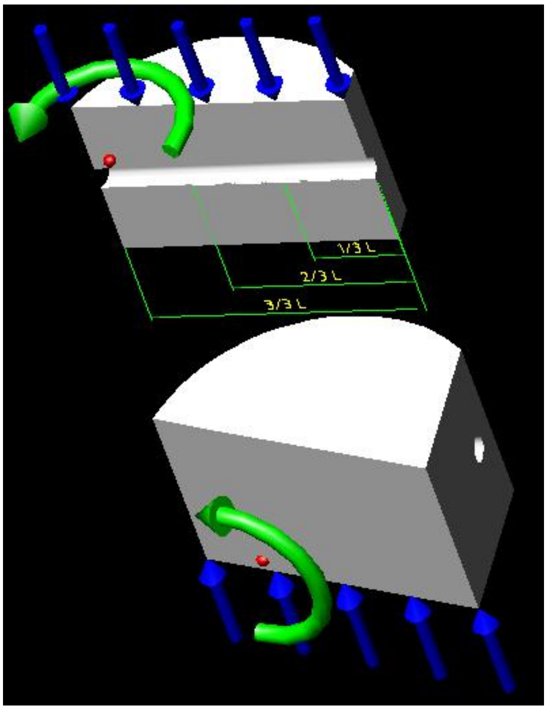

Figure 2 Graphical descriptions of the loads that the Nylacero bodies suffer.

2.4 Experimental Numerical Comparison

For the experimental part, a pig spine was used, from which the vertebral bodies L-2, L-3 and L-4 with their intervertebral discs were taken, for this effect were used two experimental techniques, one of complete field (reflecting photoelasticity) and another precise one (electrical extensometry). The first technique is applied to observe that it passes to vertebral body (in its anterior part) and second to measure the deformation in the longitudinal bars by means of an extensometric gauge. For such effect use became of equipment that counts the “Sección de Estudios de Posgrado e Investigación” of the ESIME Zacatenco, pertaining to the “Instituto Politécnico Nacional. The equipment for photoelasticity is: a polariscope of reflection model LF/Z. of the Vishay mark with its additions (Set of photoelastic lacquer and adhesive). By the extensometry part, for the fixation of the uniaxial gauges the suitable Kit was used, these had to measure deformation throughout Z, its size is considered the appropriate one (with an effective area of measurement: 1,0 x 0,8 mm, length overall: 3 mm) the gauge are of the type EA-06-03 1DE-120: with a factor of 2,6 and one electrical resistance of 120 ohms. To apply and to control the load we are used tests Universal Machine MTS model 358,10, with a nominal capacity of 24,47 KN, to acquire the data we are use scanner System 6000 of the Vishay mark and to register the data a desktop computer was used and the program "StrainSmart6000".

3 RESULTS

In figure 3, is to a graphical comparison that includes the methods experimental and numerical, which notices at first, it is that the greater gradient of differences of main stresses is located in the vicinity of the large drill through where they pass the pedicle screws. The part "A" of the figure, shows the experimental test compression to 50 kg, part "b" is the image obtained from the Ansys program of the maximum differences of main stresses, in the same conditions: in part "c" Z (longitudinal direction of the models) and part "d" are observed the stresses in corresponds to the longitudinal bar exhibiting the deformations in Z. When is not all the model of finite elements, must that the program shows the distribution of which is being requested to him in 9 regions and can happen that is not sensible to the changes that happen in the zone of interest, therefore, if the part is isolated that is desired to analyze, those nine regions are redistributed in the present elements, and is possible to appreciate the differences in these elements.

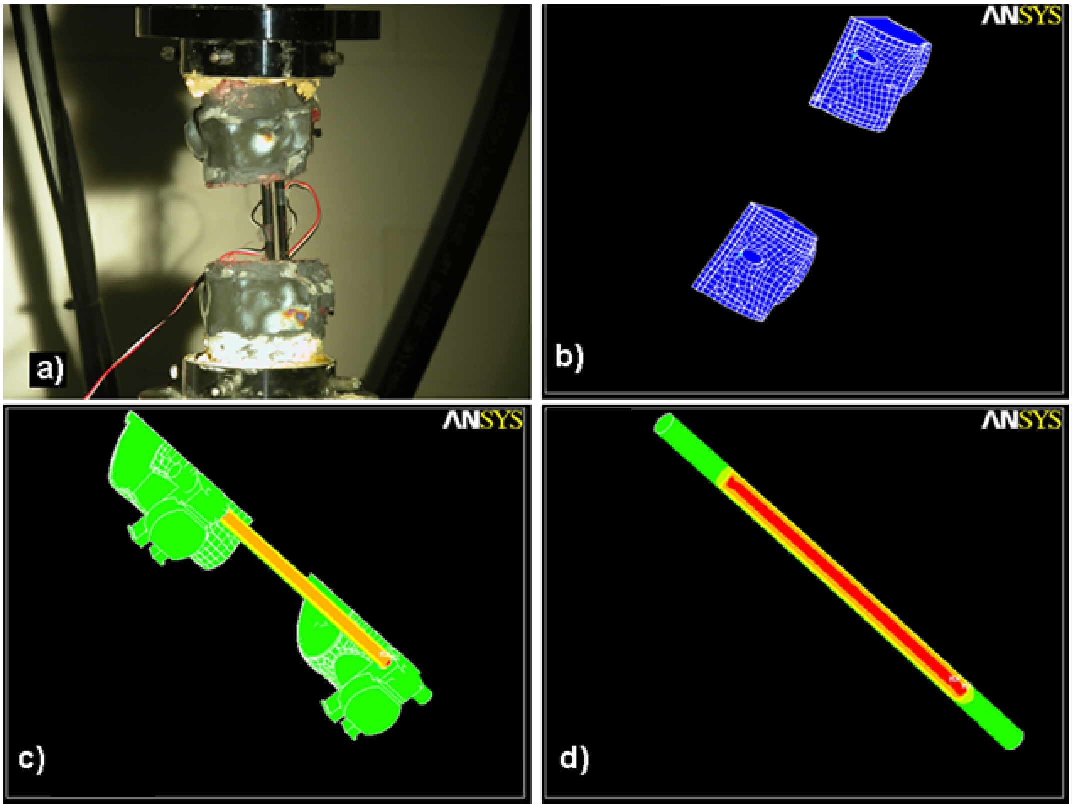

Figure 3 Tests to corpectomy total case.

On the other hand, figure 5 shows the registry taken by the System6000 equipment of the gauges adhered to the longitudinal bars in one from the tests (compression to 50 Kg.). The second test, in that the simple corpectomy total is analyzed, is most critical of the three.

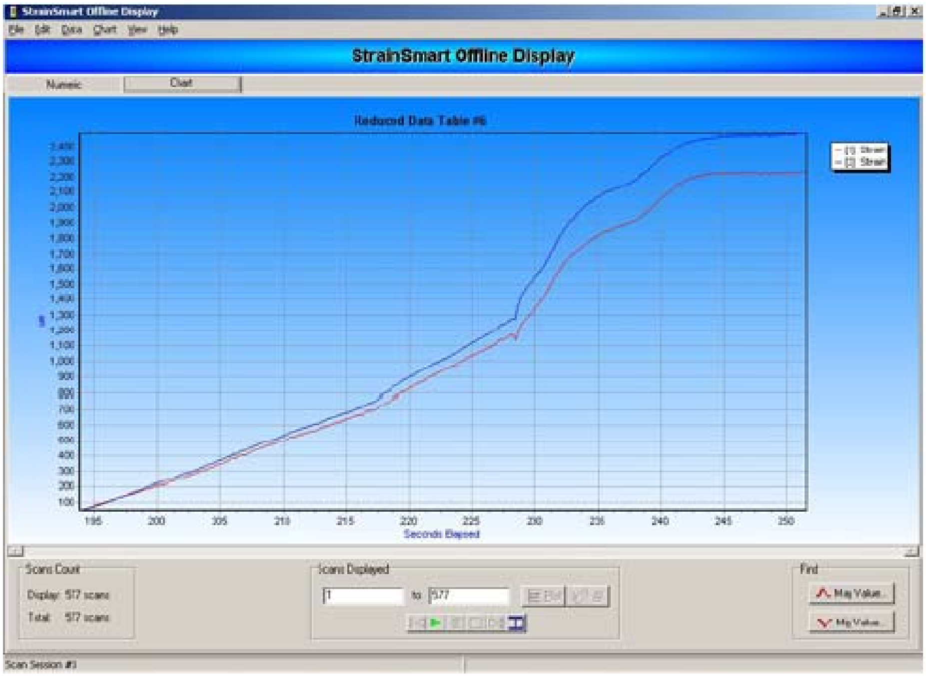

Figure 4 Strains in longitudinal bars.

In figure 5 the comparison between results obtained in Experimental form is appraised graphically and Numerical for micro strains that undergo the longitudinal bars, in the three cases, can be observed the same tendency. Case 1 is for the fixer device with all the organic structures, case 2, he is the one of the simple corpectomy total, and the 3 is the corpectomy total with anterior inserted.

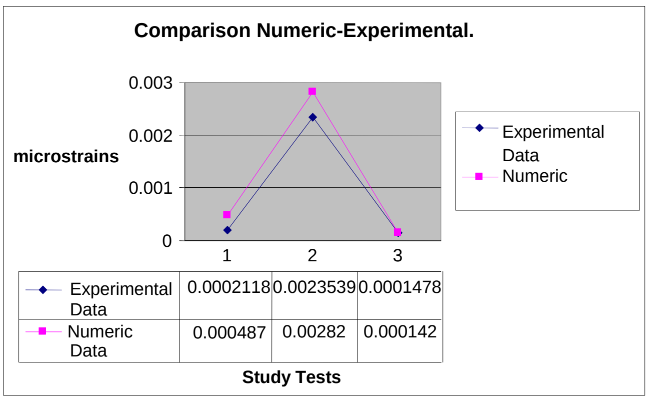

Figure 5 Results, Comparison of Experimental-Numeric data.

Table 2 and figure 6 show the results of one of the bullfights (most critical), in the following section will analyze the results.

ELEMENT:	Comp 50 Kg. Displace. (mm)	Comp 50 Kg. v M Stress	Torsion (25 N.m) Displace. (mm)	Torsion (25 N.m) v M Stress	Lateral Torsion (25 N.m) Displace. (mm)	Lateral Torsion (25 N.m) v M Stress	Combined Stresses Displace (mm)	Combined Stresses v M Stress
Cortical Bone	0.000004	0.0227	0.028432	45.4	0.001758	53.8	0.028915	58.4
Trabecular Bone	0.000003	2.0900	0.069092	15000.0	0.001604	1230.0	0.078590	15000.0
Pedicular Screws	0.000003	0.5731	0.070518	1620.0	0.001883	456.0	0.072230	1510.0
Speedboat	0.000003	2.0600	0.062318	15000.0	0.002006	1530.0	0.063946	14900.0
Longitudinal bar	0.000002	0.4987	0.070737	10700.0	0.002095	521.0	0.073029	11100.0
Hook	0.000001	0.8607	0.074296	19400.0	0.002077	1340.0	0.076704	19300.0
Transversal bar	0.000002	0.9402	0.022123	1080.0	0.002277	1340.0	0.020214	2420.0
Insert	0.000004	1.3700	0.082962	2240.0	0.002220	4210.0	0.084030	5020.0

Table 2 Results for vertebrae in corpectomy total, with insert.

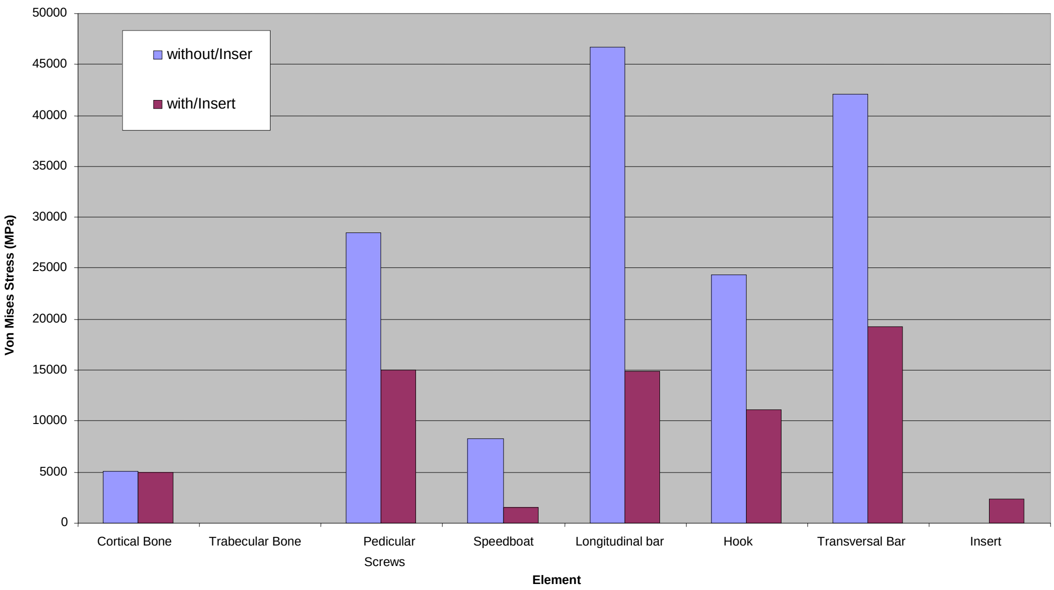

Figure 6 Results of diverse elements of inner fixer.

4 DISCUSSION

Summarizing, the following results can be enumerated:

- Of the four mechanical loads, between the simple ones, the least stress for the device it is the load of Compression, whereas the condition in which all the loads are present, is most critical.
- The more demanded elements are generally, the pedicle screws.
- If the length of pin bolt is varied, the best length, from the biomechanics point of view is the one that covers the distance with cortical to cortical in the

vertebrae bodies.

- The transversal bars contribute largely to the stability of the system.
- Variations due to the presence/absence of intervertebral discs appear. If they compare with the insert of crest iliac, this one last one is much more rigid that the combination disc-body-disc.
- The intervertebral discs are more efficient like load distributors.
- The insert of crest iliac (in anterior place) contributes in great measurement to provide a very important secondary stabilization.
- The most critical case is the one of simple corpectomy total.
- The phenomenon known like "stress shielding" appears, that is to say, the most rigid structures (fixer device) absorb or carry out part of the work that it had to make the organic structure causing weakness in the long run of these organic elements.

5 CONCLUSIONS

As a summary, two categories of experiences obtained in work the present can be considered, one is the construction of numerical models for the study of this kind of problems and two, the information reported in open Literature.

The numerical Analysis presents a great freedom in the handling of variables involved in the models.

For a suitable representation of the Models of organic structures the use of radiological images (Tomography and x-rays), provides very useful information.

The propose methodology can become extensive to other anatomical regions, as much in "Intact" State, like connected to an Implant.

There was a good correlation between the Numerical and Experimental Results.

The use of models of finite elements allows to experiment with some parameters, for example the length of the pedicular screws was proven. Also it is possible to know a complete way the biomechanics behavior of this coupled system.

Analysis of rigidity torsional in Z-axis, freedom of rotation of 3 degrees by body vertebral, so if they are the three involved bodies, the trunk is had potentially can turn 9° and according to Rohlman (1997), the body is put under a 1 or 2 N.m, this value goes of 3.6° to 7,25°, with which it is observed that indeed it happens a stiffness of the system connected in relation to the healthy body.

With the obtained results it is possible to know a complete way the biomechanics behavior of this connected system.

REFERENCES

Cunningham, B.W., Sefter, J.C., Shono, Y,. McAfee, P.C., Static and cyclical biomechanical analysis of pedicle screw spinal constructs, *Spine*,; 18(12):1677-88, 1993.

Damián-Noriega, Z., Estudio Biomecánico Experimental del Sistema Dufoo para Columna Lumbar Lesionada. Tesis Doctoral *IPN-ESIME-SEPI*, México D. F. 2003.

Kasra, M., Shirazi-AdI, A., and Drouin, G., Dynamics of Human Lumbar Intervertebral Joints. *Spine* 17:93-101, 1992.

Nordin, M., Frankel, V.H. Basic biomechanics of the musculoskeletal system, Second Edition, *Lea & Febiger*. U.S.A, 1989.

Reyes-Sánchez, A., Damián-Noriega, Z., Domínguez- Hernández, V.M., Hernández-Gómez, L.H., y Urriolagoitia-Calderón, G., Estudio Mecánico del Fijador Interno de Columna INO. Primera Parte: Comportamiento bajo Carga Cuasi-estática de Flexo-compresión, *Revista Mexicana de Ortopedia y Traumotología*, 14(1):9-15, 2000.

Reyes-Sánchez, A., Magadán, JC., Rosales, L.M,. Miramontes, V., Alpízar, A., Complicaciones de fracturas toracolumbares que tuvieron tratamiento por vía anterior. Un meta-análisis, *Acta Médica Grupo Ángeles*, 2:99–103, 2004.

Rohlman, A., Bergman, G., and Graichen, E., Loads on an Internal Spinal Fixation device during Walking. Journal of Biomechanics, 30:41-47, 1997.

Tamara-Montes, N.G., López-Villagómez, B., Anaya-Vallejo, S., Principios biomecánicos en el tratamiento de las fracturas tóraco-lumbares, *Revista Mexicana de Ortopedia y Traumatología,*; 14(1):25-33, 2000.

Tejeda, M., Anaya-Vallejo, S., Ramirez, G.R., Tratamiento Quirúrgico de las Fracturas Toracolumbares por vía Anterior, *Revista Mexicana de Ortopedia y Traumotología* 12(6):511-517, 1998.

Wang, J.L, Parnianpour, M., Shirazi-Adl, A., Engin, A.E., Li, S., Patwardhan, A., Development and Validation of viscoelastic finite element model of an L2/L3 motion segment, *Theoretical and applied Fracture Mechanics*, 28:81-93, 1997.

Wheeldon, J.A., Pintar, FA., Knowles, S., Yoganandan, N., Experimental flexion/extension data corridors for validation of finite element models of the young, normal cervical spine, *Journal of Biomechanics*, 39:375–380, 2006.

Zee, M., Hansen, L., Wong, C., Rasmussen, J., Simonsen, E.B., A generic detailed rigid-body lumbar spine model, *Journal of Biomechanics*, 40:1219–1227, 2007.