ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil

BVCDF – A NEW SURGICAL PROCEDURE APPLIED TO CEREBRAL HEMATOMA TREATMENT

Faria, A. R.
Laboratory of Mechanical Design, Faculty of Mechanical Engineering, Federal University of Uberlândia, Uberlândia, Minas Gerais, Brazil.
http://www.lpm.mecanica.ufu.br/

Roquette, A. G. D.
Faculty of Medicine, Federal University of Uberlândia, Uberlândia, Minas Gerais, Brazil.
http://www.famed.ufu.br/

Araújo, C. A.
Laboratory of Mechanical Design, Faculty of Mechanical Engineering, Federal University of Uberlândia, Uberlândia, Minas Gerais, Brazil.
http://www.lpm.mecanica.ufu.br/

Miranda, R. F.
Laboratory of Mechanical Design, Faculty of Mechanical Engineering, Federal University of Uberlândia, Uberlândia, Minas Gerais, Brazil.
http://www.lpm.mecanica.ufu.br/

Carísio, P. B.
Faculty of Medicine, Federal University of Uberlândia, Uberlândia, Minas Gerais, Brazil.
http://www.famed.ufu.br/

Guimarães, B. V.
Faculty of Biology, Federal University of Uberlândia, Uberlândia, Minas Gerais, Brazil.
http://www.biology.ufu.br/

Bression, V.
Laboratory of Mechanical Design, Faculty of Mechanical Engineering, Federal University of Uberlândia, Uberlândia, Minas Gerais, Brazil.
http://www.lpm.mecanica.ufu.br/

Lessa, S. S.
Faculty of Medicine, Federal University of Uberlândia, Uberlândia, Minas Gerais, Brazil.
http://www.famed.ufu.br/

Abstract. *An acute (ASDH) is a subdural cerebral trauma produced by high decelerations such as automotive injuries or cranial traumatisms. Actually, only the surgical treatment called Decompressive Craniotomy (DC) can be applied. This treatment is accomplished via intracranial pressure relief using a large cut in the dura mater to be possible to drain the hematoma. Unfortunately, major of end results using this technique are disappointing for low rate of functional recovery and high mortality rates observed. Here, is noted that fast subdural decompressive can causes high strain, ischemia and edges edema. Neurosurgeons associated with mechanical engineers proposed a new method for ASH treatment called Basal-Vertex Craniotomy with Dural Fenestrations (BVCDF). In this technique, small cuts are made in the dura-mater in order to reduce intracranial pressure gradually to avoid rapid subdural decompression, and avoid brain extrusion. The aim of this study was to evaluate the DC and BVCDF procedures through modeling of living tissues and finite element models to simulate the brain environment and assessing the biomechanical behavior coupled to ASH process. The modeling simulated the intracranial pressure increase under the ASDH. The DC and BVCDF procedures were also evaluated through in vitro approach. A 3D Numerical Modeling of Finite Elements using the ANSYS EF, with the Ogden hyper-elastic constitutive model also presented, results were very promising, showing up to the possibility of a quantitative comparison between the techniques. Continuing this work, other constitutive models are under analysis and implementation, in order to obtain a better assessment of the main models in the literature.*

Keywords: *Acute Subdural Hematoma, Decompressive Craniotomy, Finite element model, Modeling of Living tissue, Neurosurgery*

1. INTRODUCTION

Some types of brain trauma are generated by downturns, such as in motor vehicle accidents and can cause brain bruising bleeding in the subdural space, called Acute Subdural Hematoma (ASDH). In ASDH, bleeding (hematoma) occurs in the subdural space, usually as a consequence of the rupture of a vein cortical surface at the point where it enters the superior sagittal sinus, as shown in Figure 1.

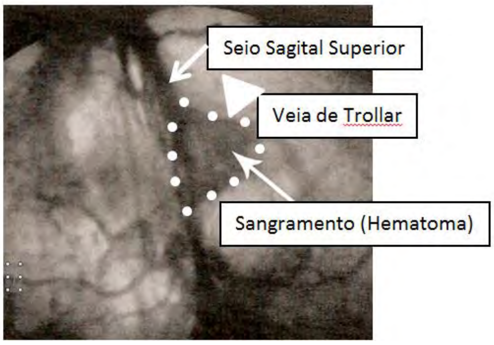


Figure 1. Image of Bleeding (hematoma) due to rupture of a superficial cortical vein.
Source: Bart D. et. al. J. Neurosurg., V 104, June 2006

One of the main factors leading to the prognosis of subdural hematoma is a marked deviation from the midline of the brain, as evidenced by the scan shown in the Figure 2.

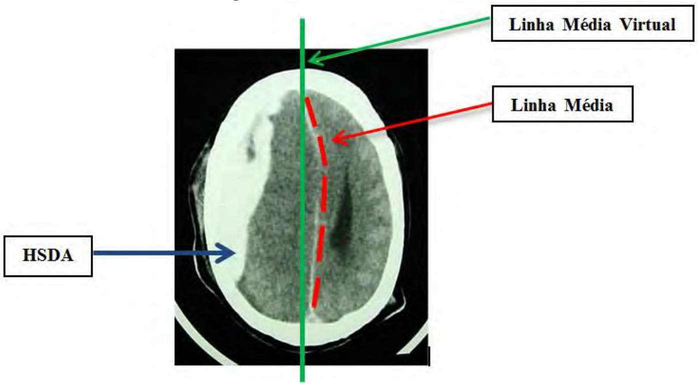


Figure 2. Computed tomography of the brain with subdural hematoma

As shown in Anatpat-UNICAMP online, subdural hematomas are found in the cerebral convexity. As the subdural space is a virtual one, but potentially large, these bruises may be very large, lens-shaped, this can be concave-convex, or biconvex when bruising at greater. It may or may not be preserved the integrity of the leptomeninges. The ASDH compresses the brain down, causing hernias. The approach of hematomas with midline shift greater than 5-10mm is surgery, drainage performed through extensive craniotomy. But it was stressed that the prognosis is grim, with high morbidity and mortality.

Depending on the clinical picture, the only treatment is a surgical procedure called a Decompression Craniotomy (DC), where the neurosurgeon looking relieve pressure through a wide opening of the dura mater in order to treat the hematoma generated in brain structures. In general, predictions or results of this technique are disappointing due to a low rate of functional recovery and mortality rates. The process of rapid decompression intradural extrusion causes a sharp brain, causing ischemia, edema and severe side bottlenecks brain tissue at the edges of the craniotomy. Neurosurgeons associated with mechanical engineers, both from the Federal University of Uberlândia, proposed a new method for treating the ASDH, called Vertex-Basal Craniotomy with Dural Fenestration (BVCDF), which is made multiple small incisions in the dura mater, to decrease gradually intracranial pressure and prevent the rapid decompression intradural.

The Figure 3 show the appearance of small fenestrations applied at the dura-mater, seeing a gradual reduction of intradural pressure.

ISSN 2176-5480

The procedure is similar to DC without complex modifications and for this reason, there is a forecast of eliminating the effect of large deformations generated in brain structures, allowing a reduction in morbidity and mortality. Both procedures, DC and BVCDF were qualitatively assessed through an in vitro approach.

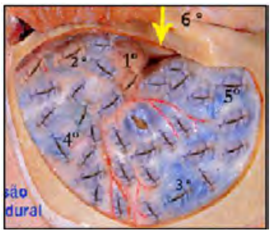


Figure 3. Dural Fenestrations for Gradual Decompression Intradural

The dura-mater is the outer membrane and the strongest of cerebrospinal surrounding the appliance (see Figure 4). It consists of dense connective tissue, adhering closely to the bones of the skull. Between the dura-mater and arachnoid there is a narrow space called the subdural space, where there is liquid.

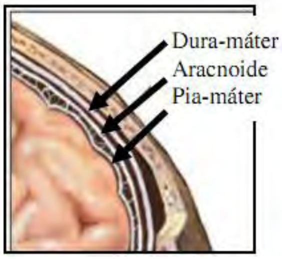


Figure 4. Details of tissue membranes (meninges).
Source: NETTER, Frank H.. Atlas de Anatomia Humana. 2ª ed. Porto Alegre: Artmed, 2000.

1.1 ACUTE SUBDURAL HEMATOMA

The intracranial pressure (ICP) is the pressure inside the cranium. It reflects the relationship between the contents of the skull (brain, cerebrospinal fluid and blood) and the volume of the skull, considered constant. Changing the volume of one of these materials may cause intracranial hypertension (ICH). The normal value of the ICP is 5 to 15 mmHg. Values between 20 and 40 mmHg are considered moderately high, and above 40mmHg, seriously high. When it reaches values above 60 mmHg, is almost always fatal. The ASDH is bleeding and accumulation of blood in the subdural space associated with the acute onset of neurologic deficits usually followed a cranio-cerebral trauma. Hematoma formation occurs most frequently in the lateral and superior aspects of a cerebral hemisphere, but may also occur in the posterior fossa and spinal canal. Figure 5 shows a representation of an ASDH compressing the brain.

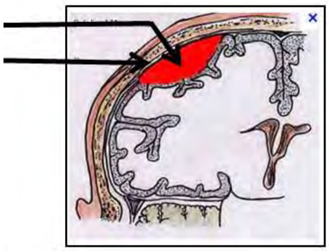


Figure 5. Representation of a ASDH compressing the brain.
Source: http://leonardoflor.blogspot.com.br/2011_11_01_archive.html.

Miranda (2009) made a study on fast and gradual compression and decompression and shows the effect of the abrupt expansion. Considered a container volume (V) containing a fluid mass (m) which exerts a pressure (p) inside the container showed that, in an isothermal process, pressure is inversely proportional to the volume and directly proportional to the mass. The increase of mass inside the container implies an increase in pressure. In decompression, the force varies linearly with the pressure and the surface area, and a sudden decompression that is, with removal of a large surface of the container, the tendency of the fluid contained in the container is out all at once , since the force of the fluid is very large. In a gradual decompression, or using small holes in the surface of the container to allow fluid can

ISSN 2176-5480

escape gradually, since the force exerted these holes is small, it allows the pressure within the container undergoes a gradual reduction.

Flower, L. (2011) showed that among the focal lesions, the ASDH is most often found, and the most common cause of mass effect of TBI. This lesion may be present in 30% of severe trauma. The lesion is unilateral in 80% of cases (bilateral in 20%) and the most common location is the region frontotemporoparietal.

Miller (1999) worked on a constitutive model for brain tissue and used finite element software to implement a linear viscoelastic model, suitable for large deformations in the polynomial form. Miller et al. (2000) conducted tests in vivo on pig brain and compared the results with numerical simulation of viscoelastic material and material hyper-viscoelastic.

The proposed solution to the problem of Intracranial Hypertension (IH) and ASDH, are hampered because the biological tissue is anisotropic, inhomogeneous, and has a non-linear relationship between stress and strain fields. Therefore, the aim of this work is to evaluate the procedures of CD and CVBDF using mathematical models in living tissue integrated finite element numerical models to simulate the brain environment and assessing the biomechanical behavior coupled with the treatment process ASDH. We analyzed the intracranial pressure increase and a possible ASDH.

2. BVCDF TECHNIQUE

The process of generating fenestrations in the dura-mater is not new. In 2001, Guilburd and Sviri have already used the process of fenestrations towards a gradual decompression at lower strain rates. They showed that patients with ASDH have higher mortality and lower rates of functional recovery compared with other patients with head injuries. Early surgical decompression and active treatment with intensive care represent, at this moment, the best way to help these patients.

Figure 6 shows the process performed intraoperatively and the work of Guilburd Sviri (2001), which shows the dura-mater after they have been created fenestration. It is observed clots subdural protruding through the apertures dural.

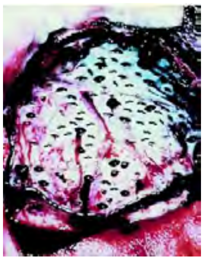


Figure 6. Process that shows the intraoperative dural fenestrations after they have been created. It is observed clots subdural dural protruding through the apertures. **Source** - GUILBURD, J. N., SVIRI, G. E., Role of dural fenestrations in acute subdural hematoma, J Neurosurg 95 (2001), 263-267, Israel.

The proposed technique has other characteristics which differ from the technique Guilburd and Sviri (2001). These features are discussed below and are shown as the effect that provides improved prognosis observed so far in cases evaluated for the ASDH:

- Osteoplastic craniotomy fronto-parietal-temporal limits vertex-basal skull;
- With the gouge or drill, excisions and smoothing the edges of the inner table of the internal craniotomy and lateral third of the great wing of the sphenoid, to the origin of the meningo-orbital artery;
- Small durotomias of 5-10 mm, the first in the lid of the Sylvian fissure, the second at the base of the temporal lobe, the third 01 cm, parallel to the superior sagittal sinus, the fourth to 01 cm above and parallel to the transverse sinus and the fifth at the base of the frontal lobe;
- Spontaneous drainage of the hematoma;
- Decompression slow and progressive brain hematoma and containment within the dural cavity;
- Irrigation and aspires to be gently with saline unheated clots on the external surfaces of the fenestration;
- Through the openings of the dura-mater direct visual inspections are performed on all surfaces exposed brain, poles and basal faces of the frontal and temporal lobes, lateral bases of the anterior and middle fossa of the skull and confluences of veins and venous sinuses;
- Several trepanation are made in the bone flap will be repositioned to loose points, aiming relieve pressure and allow drainage of the internal space for intradural and extradural subgaleal;

ISSN 2176-5480

3. MATERIAL NA METHODS

We performed a literature review on the biomechanics, the ICP, the ASDH, and the two surgical techniques, the conventional (DC) and proposed (BVCDF). Evaluation of Surgical Treatment Processes ASDH was initially performed experimentally, using the same experimental apparatus that Araújo (2009) used, when it showed that sudden expansion, system pressure, promotes a large deformation of the mass, as well as decompression promotes a gradual equalization of pressures at lower strain rates.

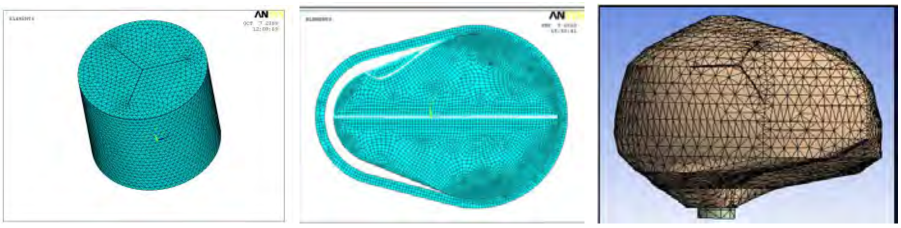
The experimental model consisting in a rigid-walled container simulating the skull, made of a PVC tube and two caps transparent acrylic material, one being a solid cylinder with a tire fitted on its bottom and another hollow for simulating the patient with the cap removed for bone surgery.

On the inside of the PVC pipe is a small Styrofoam plate attached to the air cylinder to compress the brain to the dura-mater. The brain mass was replaced by a mass of wheat flour and to simulate the hematoma was used extract from tomatoes. The dura-mater, being inflexible, was simulated by a plastic film.

The Figure 7 shows the model for the measurement of mechanical force provided by the pneumatic actuator.

Figure 7. Mechanical model for the measurement of the force provided by the pneumatic actuator

Then this assessment was done numerically in three finite element models, with ANSYS and ANSYS Workbench. In the first (See Figure 8 - a) is a 3D model and the objective was to evaluate the results of the experimental analysis and check the differences between the two processes, DC and BVCDF, qualitatively. The surgical cut in Y, or dural fenestrations were simulated. In the second (See Figure 8 - b) is a 2D model and the geometry was developed based on a horizontal plane of the head, showing the skull, dura-mater, blood, brain and a bruise located roughly to the actual structure, order to simulate a behavior closer to reality. Finally, was developed using ANSYS Workbench a 3D finite element model (See Figure 8 - c) in the proposed process (BVCDF). In this model, we used geometry closer to the real to the two sides of the brain, hematoma, the dura-mater and cervical spine, as well as simulation of surgical cutting Y-dural or fenestrations.



a) b) c)

Figure 8. a) Mesh of the first FE model. b) Mesh of the second FE Model. c) Mesh of the third FE Model.

In the third model to simulate the material in the brain, a mathematical model was used whereby the stress is related to the deformation into a hyper-elastic material, when are known only parts of the traction test of this material. It is necessary then that has the points of the tensile test, a model used hyper-elastic, and software that can calculate the constants hyper-elastic material. In this work, we used the test points "in vivo" with a pig brain investigated by Miller, K., et. al. (2000), the model of Ogden and the software ANSYS Workbench.

The software ANSYS has a number of hyper-elastic models. The user enters only points obtained in a test and choose the type of material to be applied, which express a function of strain energy, because the software itself calculates the parameters of the function. To hyper-elastic constant calculations, we used the model of Ogden.

Bertoni, F. (2009) stated that the Ogden model is the model fits the experimental data more easily, since it is not based on the stretching and deformation invariant, and most often, the data points that have to be stress versus elongation curve. He also commented that the form proposed by Ogden, free energy based on the principal stretches ($\lambda 1$, $\lambda 2$, $\lambda 3$), makes it possible to obtain these models for simplification.

In the software ANSYS Workbench must enter curve points Stress / Deformation. In the Figure 9 is shown the Stress / Deformation curve obtained in ANSYS using the test points of the work of Miller.

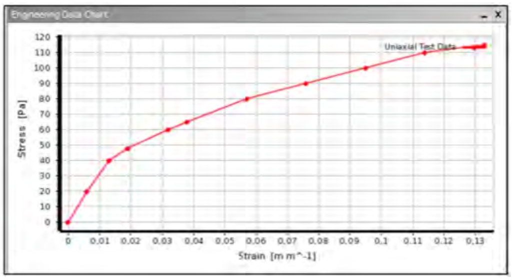


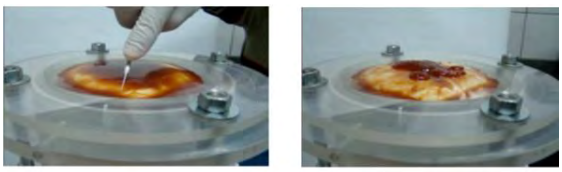
Figure 9. Curve Stress / Deformation obtained in Ansys using the work of Miller

4. RESULTS

Initially, the qualitative analysis was done using the experimental apparatus through filming and visual inspection of the effects of DC and BVCDF. The Figure 10 shows a sequence of pictures that could occur using a process similar to DC. Similarly, the Figure 11 shows the sequence of BVCDF where, among other things, are made multiple small incisions in the dura-mater.

a) b)

Figure 10. a) Early surgical cut using a scalpel. b) Final aspect of model



a) b)

Figure 11. a) Start small dural fenestrations. b) Final aspect of the model

In the first finite element model was possible to compare the results with the experiments of Araujo (2009). Figure 12 shows the vertical displacements (direction Z) of the dura-mater, the model used to simulate the CD with a load of 16N, and Figure 13 shows the vertical displacements (direction Z) of the dura-mater with 16 fenestrations, with the same loading conditions.

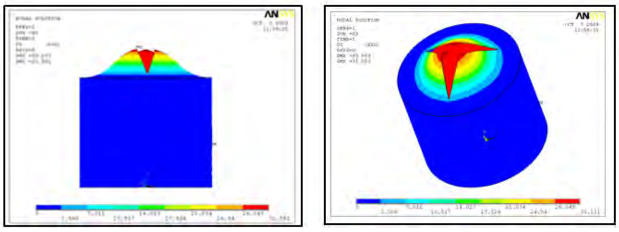


Figure 12. Vertical displacement (Z direction) of the dura-mater in the model used to simulate the DC

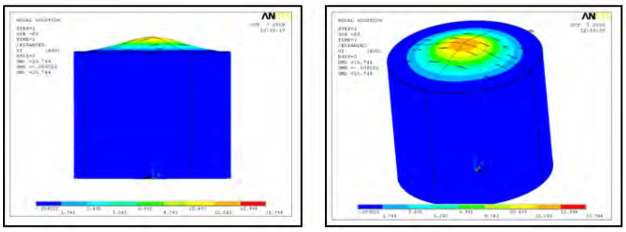


Figure 13. Vertical displacement (Z direction) of the dura-mater with 16 fenestrations

Figure 14 shows a comparison of the curve displacement Z (mm) as a function of distance from the center to a radius of 20mm, at a load of 16 N when there are 4, 12 or 16 fenestrations. Figure 15 shows a comparison of the three curves with the same DC by 20 mm.

The displacement in the Z axis of the dura-mater was maximum in the center, and fell when the distance from the center (Ray) increased, tending to zero at the ends of the cylindrical model.

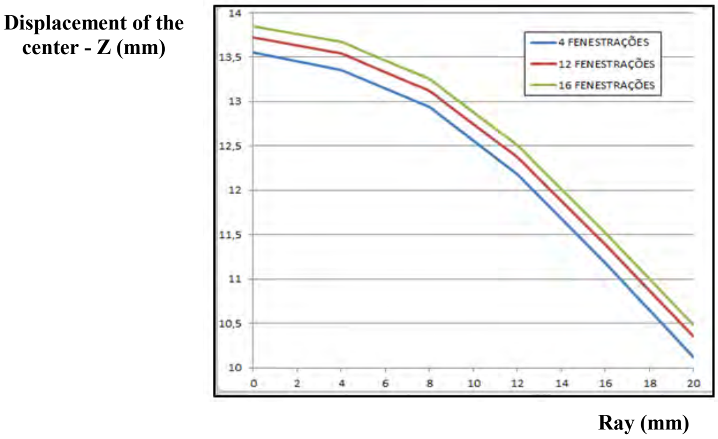


Figure 14. Displacement curve Z (mm) depending on the distance to the center (Ray), showing greater flexibility with more fenestrations

With fewer fenestrations for the same distance from the center, and the same applied load, the displacement in Z is also lower. Thus, a larger number of fenestrations allows the dura-mater to be more flexible, in other words, indicates that the network configuration can improve the overall flexibility of the dura-mater and better accommodation of brain structures.

ISSN 2176-5480

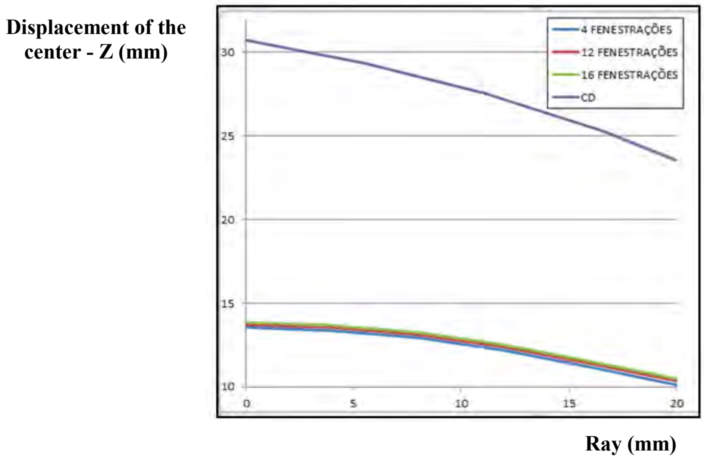


Figure 15. Displacement curve Z (mm) depending on the distance to the center (Ray), comparing with CD to the same 20mm

In addition to the large difference in displacement caused by the DC, the reduction of the displacement is fast, which can cause extrusion stroke. In the process curves of BVCDF displacement is smaller, and the fall of the displacement is slower.

This same effect was seen in the two-dimensional finite element model. The Figure 16 shows the contact region of the full 2D model, and the Figure 17 shows the vertical (direction Y) of the same model, with the maximum point in the dura-mater.

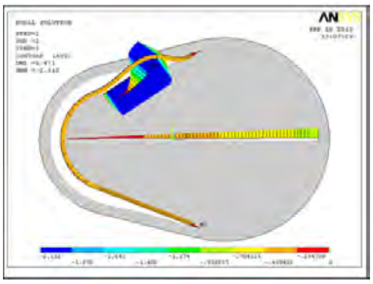


Figure 16. Contact region of the model

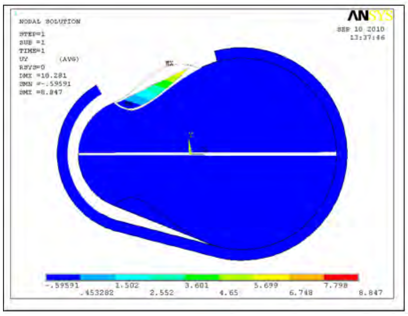
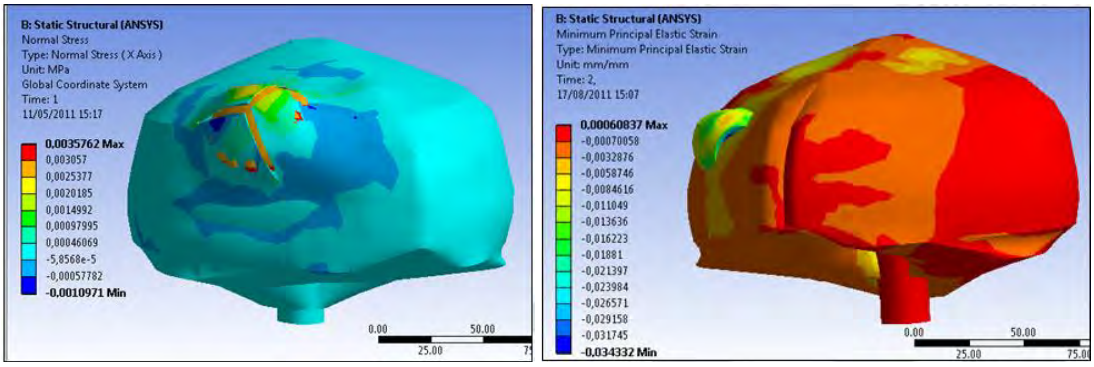


Figure 17. The displacement Y, in the model without a portion of the skull that is removed during surgery, with the maximum point in the dura-mater

A 3D Numerical Modeling of Finite Elements using the ANSYS FE, with the Ogden hyperelastic constitutive model also presented results that were promising, showing up to the possibility of a quantitative comparison between the techniques. The Figure 18 shows the normal stress in the DC, starting with the hematoma escape through the surgical incision, and the main minimal deformation and the extrusion of the hematoma due to withdrawal of intracranial pressure (ICP), and the Figure 20 shows the deformation of the dura-mater, caused by the hematoma pressure.

ISSN 2176-5480



a) b)

Figure 19. a) Normal stress. b) Main minimal deformation. Extrusion hematoma due to withdrawal of PIC.

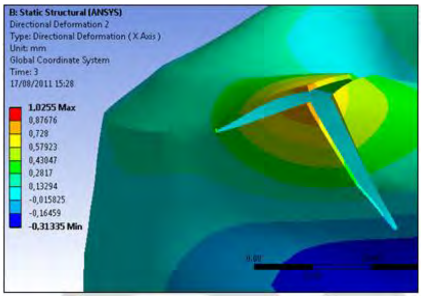


Figure 20. Deformation of the dura-mater caused by hematoma's pressure

5. CONCLUSIONS

This work aimed to propose the development of a numerical modeling of soft tissues, which is a line of research supported by mathematical and numerical models considering, in general, anisotropic conditions and large strain. This work aimed to propose the development of a numerical modeling of soft tissues, which is a line of research supported by mathematical and numerical models considering, in general, anisotropic conditions and large strain. The work aims to simulate the brain environment, seeking new understandings of their biomechanical behavior coupled with the treatment process ASDH with the conventional technique (DC) and a new proposed technique (BVCDF) evaluating the structural behavior of the system, considering the increase of intracranial pressure and possible ASDH.

The images obtained in the experimental model showed that the sudden expansion of the system pressure actually promoted a large strain rate. Such deformations to the brain could compromise the tissues and generate additional damage to persons from the hematoma.

These effects could indicate or explain the high rates of failure to the technique DC. Similarly keeping the dura-mater intact by making small cuts, the structure of the dura-mater prevent a large strain of brain mass, since the structure in "net" increase flexibility allowing leakage hematoma, however, prevents the mass is exposed and undergo large deformations. Similarly, gradual decompression promotes equalization of the pressures at lower strain rates.

The first numerical model, presented a vertical displacement (Z direction), higher in the center, and it tends to zero at its ends. This happens without cuts, with the surgical cut, or fenestrations, but only the model with the surgical cut in Y occurs extravasation brain.

It is also evident not only a large displacement caused by the difference in DC, but also the rapid decrease of the displacement, which may cause the extrusion stroke. In the process curves of BVCDF displacement is smaller, and the fall of the displacement is slower. This same effect was seen in the two-dimensional finite element model.

A 3D Numerical Modeling of Finite Elements using the ANSYS EF, with the Ogden hyper-elastic constitutive model also presented, results were very promising, showing up to the possibility of a quantitative comparison between the techniques.

Continuing this work, other constitutive models are under analysis and implementation, in order to obtain a better assessment of the main models in the literature.

6. ACKNOWLEDGEMENTS

To the development agencies (FAPEMIG, CNPq and CAPES), the FEMEC, the FAMED and the LPM.

ISSN 2176-5480

7. REFERENCES

Anatpat.UNICAMP, 2000. "Hematomas Cerebrais Traumáticos". sep. 2012. <http://anatpat.unicamp.br/taneuhematomatraum.html>.

Araújo, C. A., Miranda, R. F., Roquette, A. G. D., Lessa, S. S., Melo, L. P., 2009. "Análise qualitativa das craniotomias descompressiva (cd) e vértex-basal com fenestrações durais (cvbfd) em casos de hematoma subdural agudo". IX Encontro Interno e XIII Seminário de Iniciação Científica, Universidade Federal de Uberlândia (2009). Uberlândia, Brazil.

Bertoni, F., 2009, "Análise do comportamento dos modelos hiperelásticos em um campo de esforços reverso ao ajustado". set. 2010. <http://simeros.com/wp-content/uploads/2009/07/artigo-modelos-hiperelasticos.pdf>.

Flor, L., 2011. "Trauma Cranioencefálico (TCE)". aug. 2011. <http://leonardoflor.blogspot.com.br/2011_11_01_archive.html>.

GUILBURD, J. N., SVIRI, G. E., 2001. "Role of dural fenestrations in acute subdural hematoma". J Neurosurg 95, 263–267, Israel.

Miller, K., 1999. "Constitutive model of brain suitable for finite element analysis of surgical procedures". Journal of Biomechanics 32, 531–537.

Miller, K., Chinzei, K., Orssengo, G., Bednarz, P., 2000. "Mechanical properties of brain tissue in-vivo: experiment and computer simulation". Journal of Biomechanics 33, 1369-1376.

Miranda, R. F., 2009. "Estudo sobre Compressão e Descompressão Rápida e Gradual, e suas consequências". FEMEC – Universidade Federal de Uberlândia (2009). Uberlândia, Brazil.

8. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.