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# Deformation Analysis of Pneumatized Sphenoid Bone Caused Due to Elevated Intracranial Pressure Using Finite Element Analysis

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## Abstract

In earlier days of technology, it was not possible to understand the nature of complex biomedical problems and were only left to clinical postulations. With advancement in science today, we have tools like Finite Element Modelling and simulation to solve complex biomedical problems. This paper presents how ANSYS WORKBENCH can be used to study deformation of pneumatized sphenoid bone caused by increased intracranial pressure. Intracranial pressure refers to the pressure inside the skull. The increase in the pressure above the normal range of 15 mm hg can lead to serious conditions due to developed stresses and deformation. One of the areas where the deformation is suspected to occur is Sphenoid Bone. Moreover, the varying degree of pneumatization increases the complexity of the conditions. It is necessary to study deformation patterns on pneumatized sphenoid bone model at elevated intracranial pressure. Finite Element Analysis plays a major role in developing and analyzing model and give quantitative results..

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## I. INTRODUCTION

The sphenoid bone is considered as one of the most complex bones and is situated at the base of the skull. The sphenoid bone located in such a position that it is in intimate contact with nasal cavity, below the pituitary glands [1]. During the early stages of embryo development, all the cartilages of sphenoid bone both lateral and central which consist of Alisphenoid, greater wing lateral wing which are the lateral parts and orbitosphenoid, presphenoid and basisphenoid and other minor central parts are developed individually. Air cavities causes pneumatization of the sphenoid bone. These clinical postulations were validated using radiological support, sphenoid can be considered as most inconsistent and least accessible, with pneumatization ranging from minimal to extreme [2]. It is considered that the pressure which is exerted inside the skull on the walls of bones and the brain tissue is called intracranial pressure and it exerts a force on sphenoid bone, and it tends to deform. In a healthy adult this pressure ranges from 7-15 millimeters of mercury (mmhg) and can increase up to 25 mmhg [3]. The elevated intracranial pressure (ICP) results in the development of bone stresses and deformation. The lateral wall of pneumatized sphenoid bone is considered to be an area of interest in order to study deformation patterns.

In this paper an attempt has been made to analyse the deformation of the pneumatized sphenoid bone with respect to different sizes of pneumatized cavities using Finite Element Analysis. Also, this can be considered as an engineering support to

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clinical research analysing and the pneumatized sphenoid bone deformation. Finite Element Modelling approach has been used because of its ability to give highly accurate and precise results.

In the last few years, Finite Element Modelling (FEM) has been proven as an effective tool for modelling and simulation of biomedical systems. FEM is a tool which can be used to solve complicated biomedical problems with the help of simulation.

Finite element analysis (FEA) is a part of FEM which has applications in many fields namely heat transfer, electromagnetic potential, fluid flow, stress analysis, etc. In biomechanics FEA is used to measure stress, compression, deformation, fractures developed on bone in different conditions. FEA requires a Computer Aided Design (CAD) model to perform simulations.

## II. MATERIALS AND METHODOLOGIES

### A. Assumptions

During analysis instead of a complete skull model a slice model of laterally pneumatized sphenoid bone model was developed which was easy to understand and required less time for meshing and obtaining results.

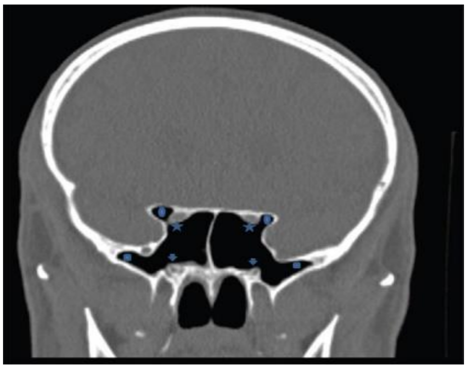

**Fig. 1 CT Scan of Pneumatized Sphenoid Bone**

### B. FEA

The following steps were carried out to design a sliced model of lateral sphenoid bone out of CT scans and application boundary conditions:

#### 1. CT Scan

CT images of pneumatized sphenoid bone were obtained from open source platform. Fig. 1 represents one of the CT images. No patient information was breached. Outlines of CT images were extracted in CAD software.

#### 2. CAD Model

The CAD model of lateral pneumatized sphenoid bone was created from open source CT scan data and was reconstructed in a software ANSYS Mechanical. As the pneumatized sphenoid has a nonlinear structure a symmetric model was created to reduce the complex structure. We can see a relatively simplified model in Fig. 2. The simplified model was created with respect to the CT scans. The reason behind developing a simplified model was to reduce complexity and for the better understanding of deformation values which were observed. The assignment of material values of cortical, cancellous and brain was not possible in CT model therefore it was necessary to develop a simplified model in which material properties could be assigned. Assigning the material values gives a better idea of bone deformation. For evaluating extent of pneumatization, models with varying cavity lengths were designed


**Fig. 2 Simplified Model of Sphenoid Bone**



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## III. MATERIAL ASSIGNMENT

Physical properties in a structure are derived based on the constituent material. These properties can be classified as isotropic, transversely isotropic, orthotropic, and anisotropic [4]. Human bone displays anisotropic behaviour but for the simplification, isotropic properties were taken into consideration. Skull model consist of cancellous and cortical bones and the properties of both the bones were taken into consideration. Following Table I display the mechanical properties used for modelling the sphenoid bone model.

**TABLE I**

**Mechanical Values For Bone Properties [9]**

| Properties | Materials | | |
|---|---|---|---|
| | *Brain* | *Cancellous* | *Cortical* |
| Density ($kgm^{-3}$) | 1050 | 1800 | 1300 |
| Young's Modulus (Pa) | 7500 | 18200000 | 15000 |
| Poisson Ratio | 0.5 | 0.25 | 0.33 |
| Bulk's Modulus (Pa) | 2090 | 1.21E+08 | 14706 |
| Shear Modulus (Pa) | 2500 | 7.28E+07 | 5639.1 |

### 4. Mesh

FEA mesh represents the nodes and elements for structural calculations on 3D CAD model. Mesh was generated using the auto-mesh generation algorithm in ANSYS. Mesh was made of tetrahedral elements [5], it contained 5296 nodes and 1400 elements. Mesh refinement was performed to yield accurate results. Fig. 4 represents the meshed structure.

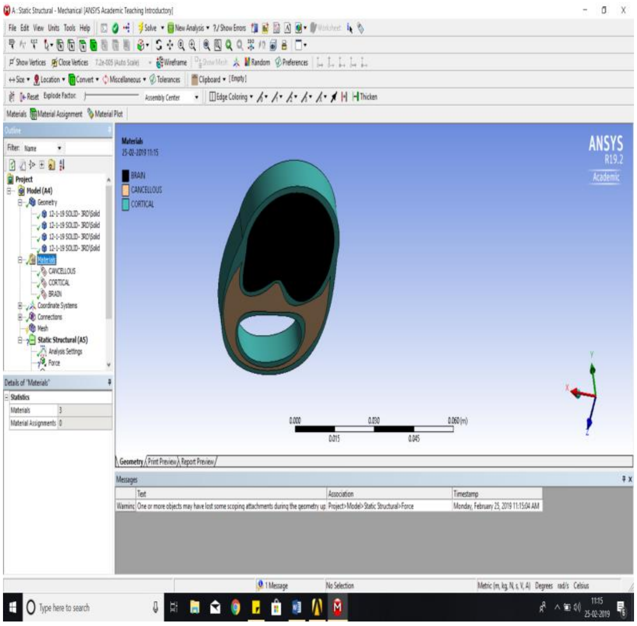

**Fig. 3 Assignment of Bone Properties on Developed Model**

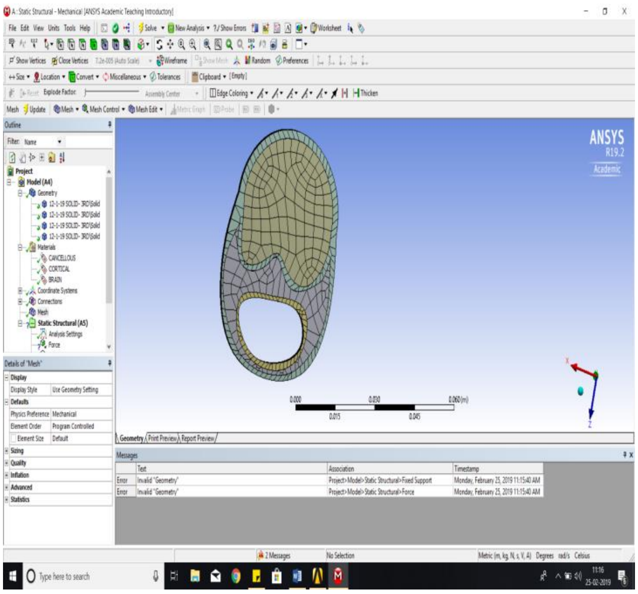

**Fig. 4Meshed Model**

### C. Boundary Conditions

Since the system is assumed to linear elastic model, to determine the modal response using FEA Hooke's

Law is taken into consideration [6].

Hooke's equation is applied in situations where an elastic body undergoes deformation. Isotropic materials are assumed to be analogous development for viscous fluids. Isotropic materials are independent of direction. For isotropic material general, Hooke’s law can be represented as follows,

$$\sigma ij = 3K\left(\frac{1}{3}\right)\varepsilon kk\delta ij + 2G\left(\varepsilon ij - \left(\frac{1}{3}\right)\varepsilon kk\delta ij\right) (1)$$

where K = Bulk modulus; G = Shear modulus.

Hooke’s Law for isotropic material in terms of Young’s Modulus and Poisson’s ratio can be written as [7]:

$$\varepsilon ij = \frac{1}{E}\left(\sigma ij - v(\sigma kk\delta ij - \sigma ij)\right) \quad (2)$$

During performing analysis on geometrical model of sphenoid bone a fixed boundary condition was used instead of a free condition. Fig. 5 shows the loading condition and fixed support assignment. Exterior part of the model was given a fixed support. ANSYS 19.2 workbench was used for analysis and the force over the area of interest was selected by as load. Deformation analysis was performed for the varying amount of forces corresponding to estimated elevated pressure, since

P=F/A (3)

F= force and A= area

And deformation is given by the equation:

D= (F/A) *(L/E) (4)

L= length or thickness in meter; E= young’s modulus in Pascal

F/A= pressure in Pascal.

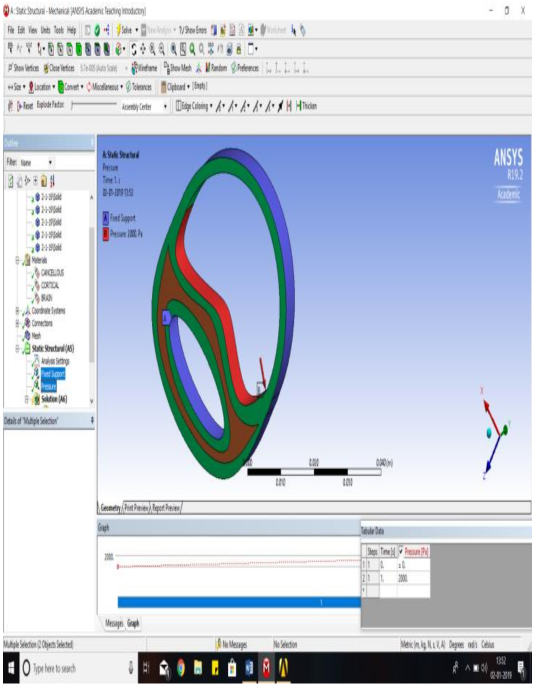


**Fig. 5 Assignment of fixed support and loading conditions**

## IV. DEFORMATION ANALYSIS

Deformation analysis of the sphenoid bone using FEM is a key to understanding the behavior of sphenoid bone when a force is exerted upon it by ICP. With the amount of increasing force, the cavity length was altered in order to study the effect of pneumatization of the degree of deformation. The area of interest had an area of 0.0004791698 $m^2$, and the force was calculated for the pressure range of 10 mmhg to 35 mmhg.

**TABLE II**

**Loading Conditions**

| Sr. no. | Loading Conditions | | |
|---|---|---|---|
| | *Force* | *Pressure(mmhg)* | *Pressure ($N/m^2$)* |
| 1. | 0.6388 | 10 | 1333.22 |
| 2. | 0.9582 | 15 | 1999.84 |
| 3. | 1.2777 | 20 | 2666.45 |
| 4. | 1.5971 | 25 | 3333.06 |



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| Sr. no. | Loading Conditions | | |
|---|---|---|---|
| | *Force* | *Pressure(mmhg)* | *Pressure ($N/m^2$)* |
| 5. | 1.9165 | 30 | 3999.67 |
| 6. | 2.2359 | 35 | 4666.28 |

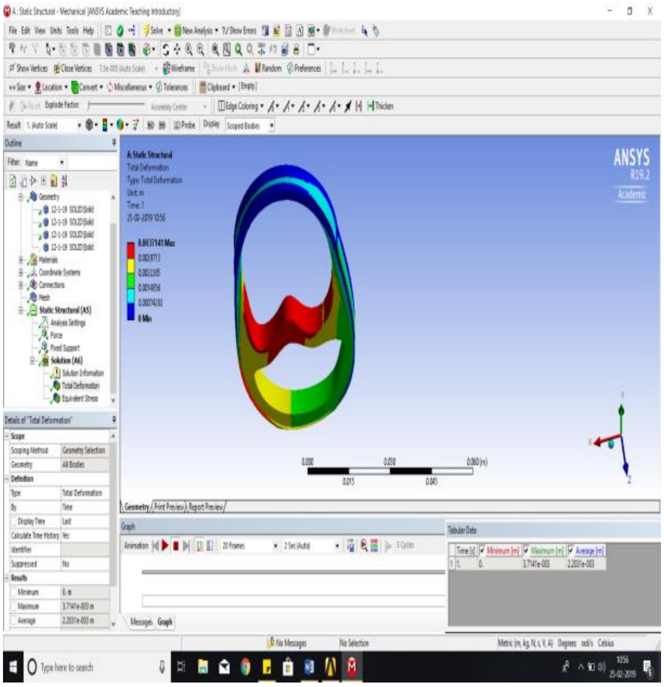

**Fig. 6 Deformation Results on the Model**

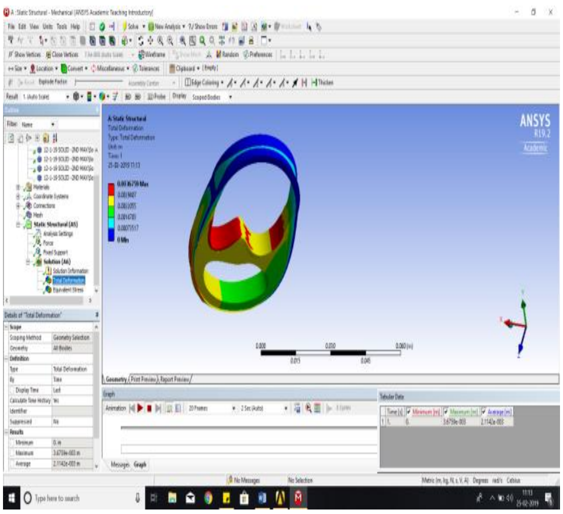

**Fig. 7 Deformation Results on the Model**

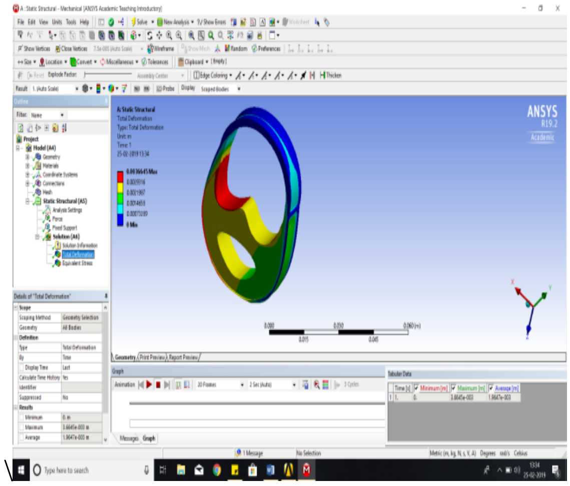

**Fig. 8 Deformation Results on the Model**

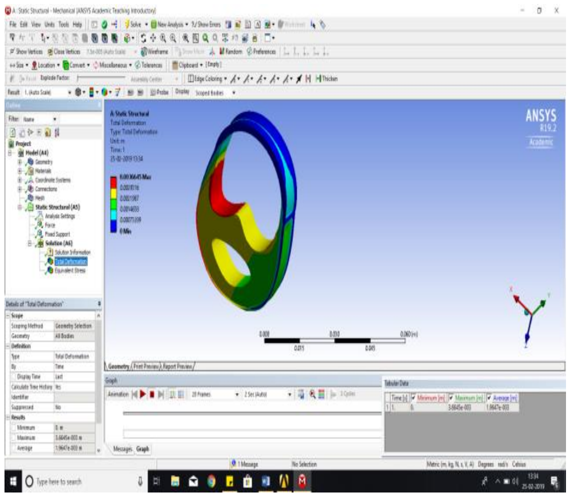

**Fig. 9 Deformation Results on the Model**

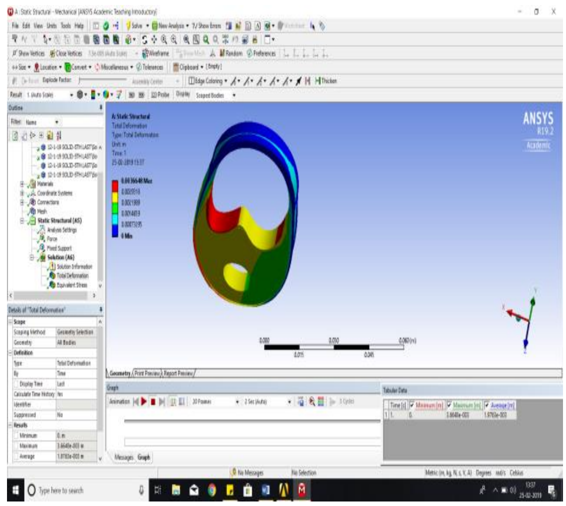

**Fig. 10 Deformation Results on the Model**

Fig. 6,7,8,9,10 shows the simulated results for



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deformation. When force was exerted on 3D model, it showed a deformation around the area of interest. Also, with decreasing cavity length the deformation was reduced to some extent.

## V. RESULTS AND DISCUSSION

The results obtained after simulation were in connection with the clinical postulations. When elevated ICP exerts a force on the pneumatized cavities of sphenoid bone it causes further deformation of the bone which can be seen in Fig. 6. This situation can lead to more serious problems due to structural and physical changes of the sphenoid like spontaneous CSF leak, meningoencephalocele which are clinically postulated as an effect of Sphenoid bone deformation [8]. Using a simulation tool, it can be clearly seen and the point can be supported that pneumatized sphenoid bone undergoes a deformation when a force is exerted on it. After acquiring the deformation values, it was seen that the deformation increased with the increase in pressure and also the size reduction of pneumatized cavity showed a minor dip in the deformation.

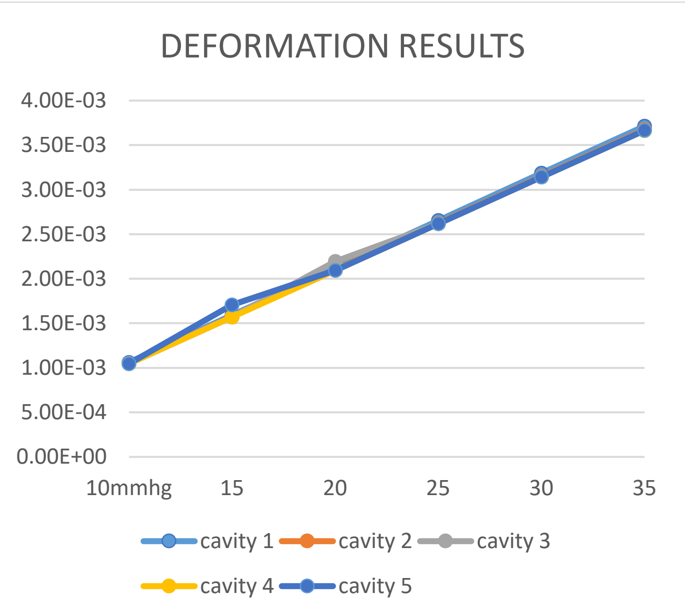


**Fig. 11 Graph of Deformation for different Cavities**

**TABLE III**

**Deformation Values Corresponding To Developed Pressure**

| Pressure(mmhg). | Deformation | | | | |
|---|---|---|---|---|---|
| | *CAVITY 1* | *CAVITY 2* | *CAVITY 3* | *CAVITY 4* | *CAVITY 5* |
| 10 | 1.0611E-3 | 1.0502E-3 | 1.0478E-3 | 1.0469E-3 | 1.0460E-4 |
| 15 | 1.5917E-3 | 1.5753E-3 | 1.5717E-3 | 1.5704E-3 | 1.7050E-4 |
| 20 | 2.1224E-3 | 2.1006E-3 | 2.1958E-3 | 2.0942E-3 | 2.0942E-3 |
| 25 | 2.6530E-4 | 2.6257E-3 | 2.6197E-3 | 2.6175E-3 | 2.6176E-3 |
| 30 | 3.1836E-3 | 3.1508E-3 | 3.1436E-3 | 3.1410E-4 | 3.1410E-4 |
| 35 | 3.7141E-3 | 3.6759E-3 | 3.6675E-3 | 3.6645E-4 | 3.6648E-3 |

## VI. CONCLUSION

Using a slice model of the sphenoid cranium structure, a basic set of values can be simulated corresponding to pressure applied by the Cerebrospinal Fluid at the targeted areas. These results are, however, viable assuming some fixed biological factors such as properties of bone, CSF and selecting some variable physical factors such as force; incident on the most simplified calculable model with fixed assigned presumed properties. It is difficult to use ANSYS FEA to portray the after effects of a ruptured pneumatization because of the isotropic nature of the material assigned to the model as an assumption. However, it highlights the areas of interest on the sphenoid bone where the deformation is maximum. These areas match the areas examined during clinical observations while analysing and diagnosing multiple congenital, acquired disorders or even repercussions due to accidents, thus, giving calculative and quantifiable



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proof to subjective diagnosis.

## VII. FUTURE WORK

In current model, only a slice of pneumatized sphenoid bone is taken into consideration for performing analysis and simulation. The model was designed only on the outline and not extracted from the active CT scans. More accurate results can be obtained by extracting the minute details from the slices. In the present work, only a slice model was constructed because analysis of entire skull model is complex and requires high configuration computers to obtain simulation results. In this model normal force is applied on suspected areas to see deformation but, in vivo CSF has a pulsatile flow which exerts intracranial force. It would be of interest to incorporate above factors which can give a better idea about some of the errors in this model. The results obtained by such method can be used as indicative to support clinical observations. These observations may be further studied and narrowed into symptoms during diagnosis of neurological disorders caused due to structural damages of the sphenoid bone.

## VIII. CONTRIBUTION

DrDileshMogre during his clinical practiced realized people with pneumatized sphenoid bone have more chances of spontaneous CSF leak, this thinking matched with the clinical postulations and research work done earlier in this topic.

With help of Dr. JitendraToravi it was realized how the CSF fluid must be flowing causing the bone deformation. He helped in application of Hooke’s Law on the complex system

Saurabh Joshi was in charge of the modelling and rendering of the sphenoid bone and conducting literature survey.

PruthaDeshpande carried out the part of material assignment, meshing and application of boundary conditions on the model

Aishwarya Kura conducted the final step of simulations for various loading conditions and interpreted the results

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