

ORIGINAL ARTICLE / ORJİNAL MAKALE

ANALYSIS OF AXIS TRAUMATIC SPONDYLOLISTHESIS
BY FINITE ELEMENT METHOD

AKSİS TRAVMATİK SPONDİLOLISTEZİSİNİN SONLU ELEMANLAR YÖNTEMİ İLE ANALİZİ

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SUMMARY

Aim: Hangman's fracture is fracture of the second cervical vertebra that separates anterior and posterior elements of the vertebra. There are very important biomechanic results of Hangman's fracture. Finite element method is the most frequently used mathematical for cervical vertebrae.

Material and methods: Simulation within this study, it has been studied to have more comments about the Hangman's fracture that is seen clinically; mechanism and localization of the Hangman's fracture has been tried to study by linear static analysis and migration and tensile analyses have been done. From atlantodental joint surface, parallel to the axial plane of dens axis, considering that there is a 1000N bending force transmitted from atlas; and finite elements method is used.

Results: Results of our study are accordance with results of experimental cadaveric studies. Thus, it has been observed that this study proves the accuracy of admittances in the analysis by quantitative method, limitation conditions, loadings and selected element types.

Conclusions: Instead of using an expensive cadaveric method or methods with different in quality, by finite elements method, it would be possible to examine the trauma detailed and with high sensitivity.

Key words: Axis, Traumatic spondylolisthesis, Hangman's fracture, Finite element method

Level of Evidence: Experimental study, Level II

ÖZET

Amaç: Hangman kırığı vertebra'nın ön ve arka elemanlarını ayıran 2. servikal vertebra kırığıdır. Hangman kırığı ile ilişkili çok önemli biomekanik değerlendirmeler vardır. Servikal omurganın matematik modellerinin en sık kullanılanı, sonlu eleman metodudur.

Gereçler ve yöntem: Bu çalışma kapsamındaki simülasyonda, klinikte görülen asılmış adam kırığına daha net bir yorum getirebilmek için asılmış adam kırığının lokalizasyonu ve mekanizması lineer statik analiz ile incelenmeye çalışılmış, yer değişimi ve gerilme analizi gerçekleştirilmiştir. Atlantodental eklem yüzeyinden dens aksisin aksiyal düzlemine paralel olacak şekilde, atlas kemiğinden aktarılan 1000 N'luk bir eğme kuvveti geldiği varsayılarak ve sonlu elemanlar yöntemi kullanıldı.

Sonuçlar: Çalışmamız kadavra çalışmalarının bilinen deneysel sonuçlarına uyum göstermiştir. Sayısal yöntem ile yapılan analizde kabullerin, sınır şartlarının, yüklemelerin ve seçilen eleman tiplerinin doğruluğunu kanıtlar nitelikte olduğu görülmüştür.

Sonuç: Bu yöntemde, travma modeli ile ilgili araştırmaların yapılmasında, kadavra modeli gibi masraflı ve birbirinden nitelik olarak farklı yöntemlerin yapılması yerine sonlu elemanlar yöntemi kullanılarak, travma, ayrıntılarıyla ve hassasiyetle incelenebilmektedir.

Anahtar kelimeler: Aksis, Travmatik spondilolistezis, Asılmış adam kırığı, Sonlu elemanlar yöntemi

Kanıt Düzeyi: Deneysel çalışma, Düzey II

INTRODUCTION:

Although the developments in patient care, surgical technics, prevention of complications and rehabilitation in the last few years, cervical region injuries are still the important causes of disability and death. Generally the traumatic spondylolisthesis of axis occurs in the traffic accidents, diving and fallings with

the rate of 4-8 % of all cervical injuries (5,7). Hangman's fracture is the fracture of the second cervical vertebra (2,13).

There are very important biomechanical considerations associated with Hangman's fracture. Models that has been using in cervical biomechanical experiments are cadaveric and mathematics types frequent-

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ly. Finite element method is the most frequently used model among the mathematical models of cervical vertebrae (16,17).

Simulation within this study, it has been studied to have more comments about the Hangman's fracture that is seen clinically; mechanism and localization of the Hangman's fracture has been tried to study by linear static analysis and migration and tensile analyses have been done.

MATERIALS AND METHODS:

Obtaining for necessary initial geometry of surface model of the axis, axis bone of 30 years old healthy man scanned with 1mm sequenced sections by using Siemens Somatom Plus-S axial tomography. Sections obtained from tomography were arranged by using Mimics 7.0 software; and the first geometries obtained such as necessary surface to begin the design of C2 and dot cloud. Obtained geometries are shown in Figure-1.

As a result of the scan, these data evaluated into Initial Graphics Exchange Specification (IGES) format by using Mimics 7.0 program to make it possible to exchange the information into other formats to use with different software. These IGES formatted data is

used as an initial for obtaining a finite elements network by unlocking with CATIA V5R9 soft ware. Firstly the geometry has been arranged since the surfaces that are obtained by Mimics 7.0 cause problems during the finite element network obtaining.

Arranging the Geometry (CAD) (Computer-aided design):

For arranging the geometry, CATIA V5R9 software was used that it is a multi functional, computer-aided design, production and engineering (CAD/CAM/CAE) software. By the profit of surface modeling skills of CATIA V5R9 helped for remodeling and correction the defective surface of the axis.

-ANALYSIS:

Element types of C2 Model:

In C2 model, elements that have linear structure functions were used. Reasons these are that functionally high grade elements cause problems during the network occurrence because of their complex geometry, and a great amount of the structure is equipped with an discontinuous and irregular finite element network. Certain specifications of the elements that were used in the analysis are given below:

a) Cortical Regions – Shell 63 Element: Determinations of cortical bone have been performed by

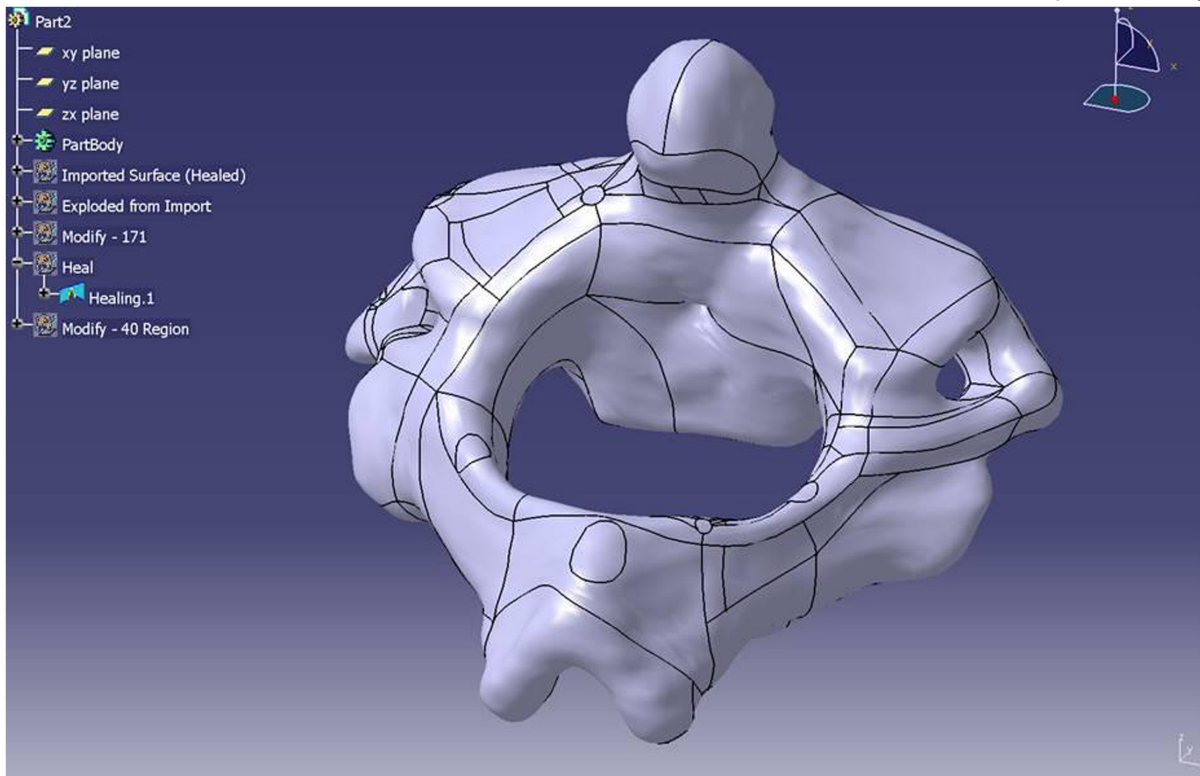


Figure-1. By arranging the defects of Axis geometry, an indoor volume has been generated, and with the help of this volume, 3D model of axis has been obtained. Obtained model is shown in the figure.

Shell 63 element that has both bending and membrane sufficiency capabilities.

b) Trabecular Bone – Solid 45 Element: It is used for 3D modeling of solid structures. Element is determined with 8 loops that are 3 degree free for each (translation in X,Y,Z directions). Element has plasticity, stress stability, fluctuation, penetration, wide deflection and wide straining qualifications. Element can be determined with 8 loops and orthotropic material properties.

Qualifications of the Analysis and the Admittances:

To solve the problem with finite elements method, some data are necessary for entered to the computer; coordinates that generate the geometry of the inspecting material, convenient element type selection, segmentation of the geometry into elements, properties of the model generating materials, external factors applied to model (applied force and direction), limitation conditions of the geometry (support coordinates and direction), type of analysis (dynamic, statics, electromagnetic), geometry, evaluated into the right structure for analysis media from CATIA. Shell 63

and Solid 45 has been chosen as element types.

In the simulation as an extent of this study; localization and mechanism of Hangman's fracture was tried to be studied with linear static analysis. In linear static analysis, it is accepted that; tensile-structure changing linkages of the materials are linear, all manner during the analysis occur in the elastic zone, properties of the material do not change by time, transposition amount is very small, applied weights are slow enough to not to have an inertial force and tensile state is time-independent.

As a result, by examining the tensile state, initiation and progression pathways of the fracture were studied. Thickness variations at cortical bone ignored and determining 1mm thickness on the surface of all bone, a shell finite network obtained from SHELL 63 elements. Since the geometry is complex, all shell elements generated in triangular form and tried to optimize the network convenience, and also tried to minimize the local errors. Trabecular bone is meshed with tetrahedron SOLID 45 elements. Finite element network generating

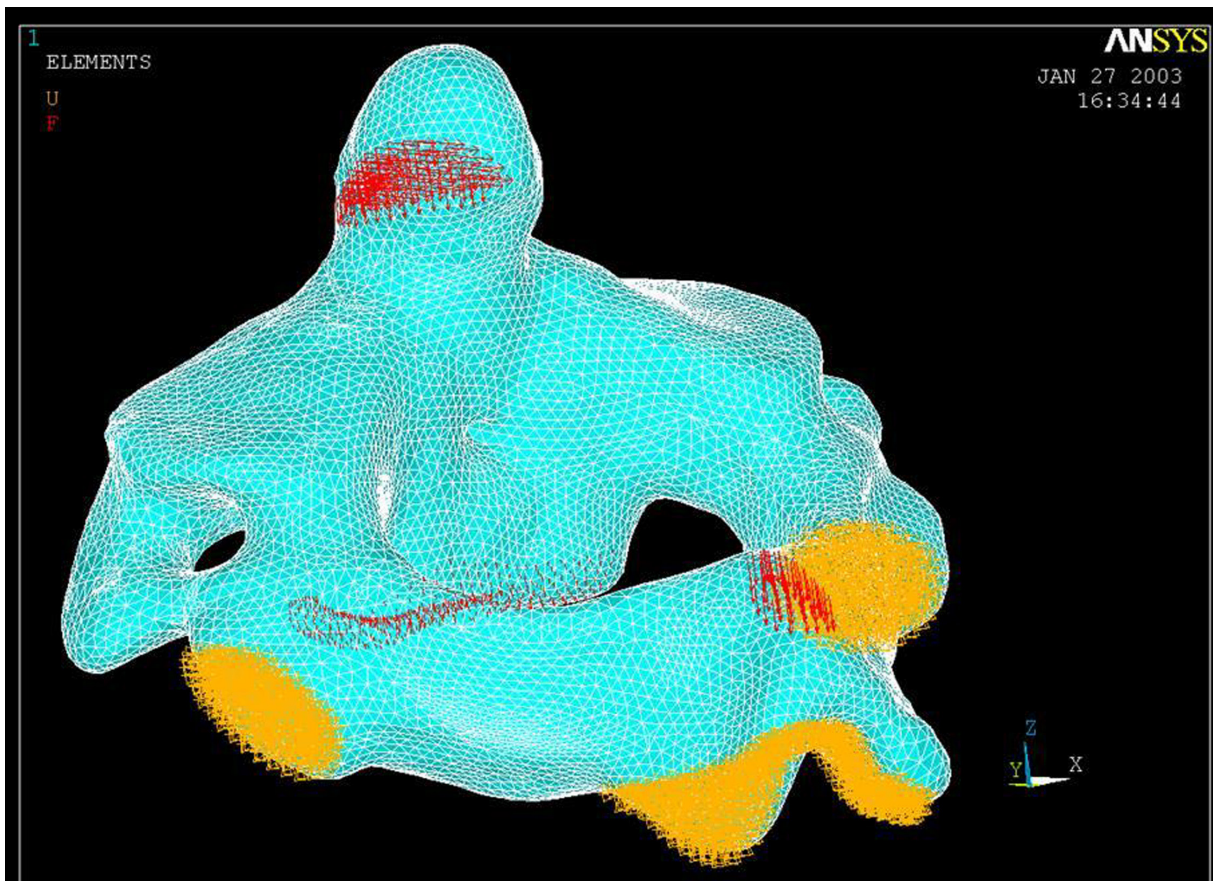


Figure-2. View of applied forces and comparative limitation conditions of finite element networks generated by 2.0 mm and 1.0 mm elements.

procedures, analyses and visualization steps of the results have been performed in ANSYS environment.

Limitation Conditions and Applied Forces:

Examining the anatomy of C2 bone in despite of Hangman state, bearing regions and force stream ways were studied. According to this state, since the surfaces of the facet joints lean and stabilize on C3 bone facets, actions at every free degrees and at all loop points on these surfaces, have been blocked (Embedded Bearing). Since inferior side of spinous process of C2, leans and stabilizes on C3 bone, this region has bared as embedded.

Simulating lineages of inferior surface of the corpus of C2 to C3, and according to literature, as an close resistant force value 340 N has been distributed to the nodes on this surface. Parallel from atlantodental joint surface to axial plane of axis, C1 bone was considering as a generator of 1000N force as a bending force. As a result of a lineages coming from atlas, top of the odontoid process charged with 340N which is an average binding resistance. Charging state views is given in Figure-2.

Determining 1000 N force was consistent with to the literature (bond tensile force according to literature at + C2 1000 N experimental article) with these admittances (12). On the other hand, for a person who falls down from a certain height, falling speed is $V = \sqrt{2gh}$ and approximate force at the hit moment is

$F = (\Delta t / \Delta V) m$. 1000 N is an Hangman's physiology consistent analysis force approach for approximately an 80kg person who falls down from 0.7 meter height and with the rope resilience, reducing the velocity rapidly from 0.3sec to 0.

Material properties of bone, consistent with the literature samples (Young's modulus, Poisson rate and bone density) were considering the bone completely with its cortical and spongy bone qualifications; it determinates different from trabecular bone. Spongy bone, because of its porous and irregular properties, is anisotropic.

Studies showed that anisotropy at spongy bone can be ignored. Thus, according to the results of our study, spongy bone may be accepted as homogenate material.

According to the approach of linear attitude aspect of materials, for cortical and trabecular bone, material properties are accepted as on Table-1.

Table-1. Characteristics of materials were accepted as below for cortical and trabecular bones, according to their linear behaviour.

	Cortical Bone	Trabecular Bone
Module of Elastisite (E)	10 GPa	1 GPa
Poisson Ratio (ν)	0.3	0.3
Density (σ)	1300 kg/m ³	130 kg/m ³

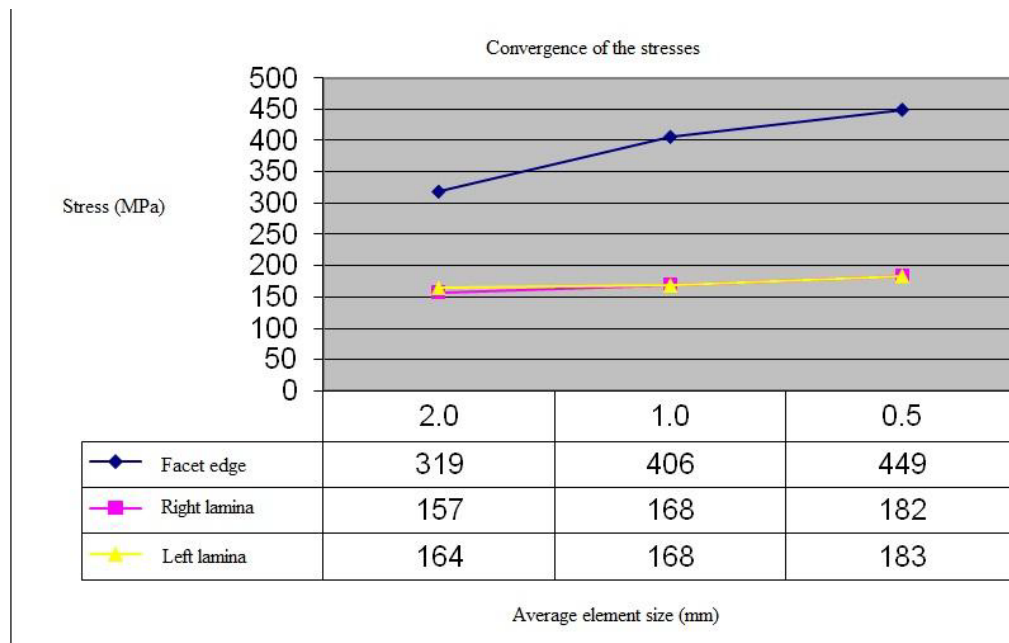


Table-2. The table shows loop node numbers and amount of elements for each element sizes for cortical and trabecular bone.

RESULTS:

In finite element solutions, one of the most important criteria is to consider the sensitivity of the obtained solutions to finite element network's average element dimensions. This event named as convergence. Ideal element dimensions must be chosen as small as possible. But in a real situation, an optimization is necessary because of the increasing in computer source needs and also increase in the number of the elements with the numeric errors. Sensitivity to the extents, especially in linear elements 160 has a vital importance, increasingly, because the derivation values that are been using in the calculation of this

kind of tensile show no continuous state. At the same limitation conditions and with the same material the observed C2 model meshed with 3 different sized element and analyzed separately. Loop node numbers for each element sizes and amount of elements is given for cortical and trabecular bone in Table-2.

Maximum tensile strength values obtained from these analyses and high tensile at certain points is given for each element sizes in Table-3, Figure-3,4. Total sum of the motions of the bone and the variation of element sizes of the intersections is given at Figure-5.

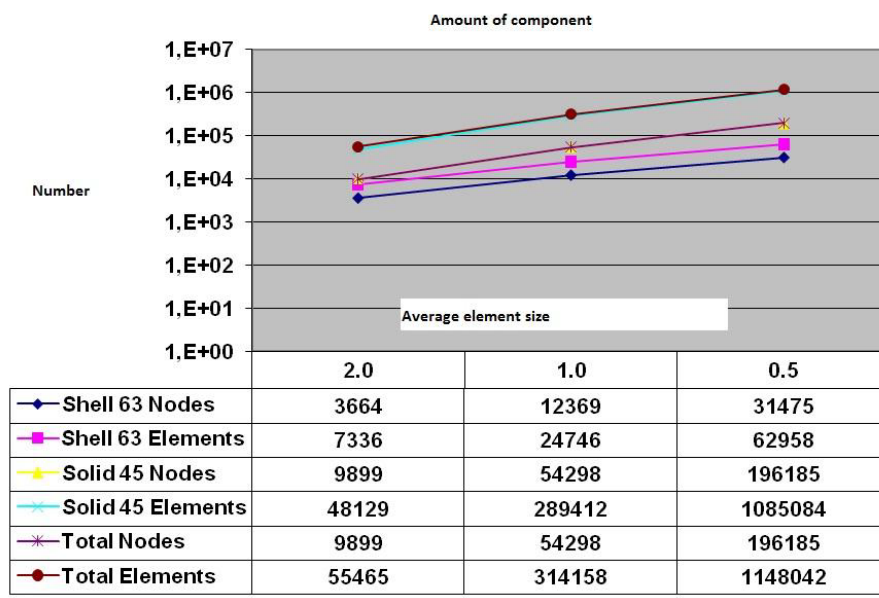


Table-3. The figure demonstrates variations according to size of element of maximum tensile strength values and high tensiles at certain points obtained from these analyses.

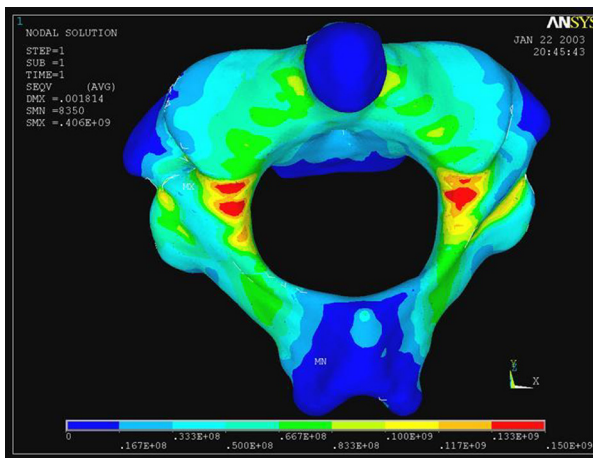


Figure-3. Finite Element Solution generated by 1.0 mm elements – Tensile Contours (Top view).

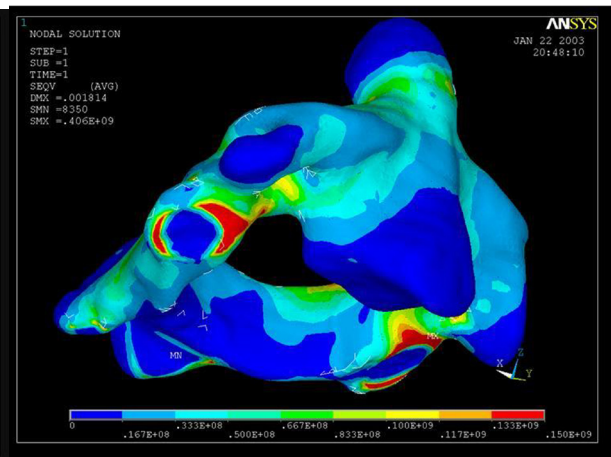


Figure-4. Finite Element Solution generated by 1.0 mm elements – Tensile Contours (Bottom View).

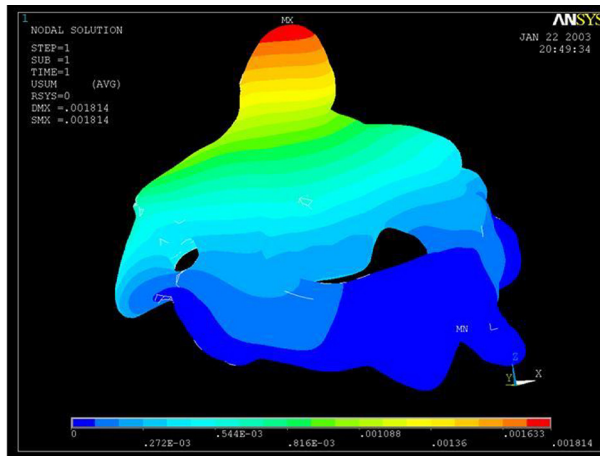


Figure-5. Finite Element Solution generated by 1.0 mm elements – Total Displacement Contours (Oblique View).

It is seen that obtaining a finite element network by 2 mm average element size, is not successful at simulating the real state. It is observed that 1mm meshes are better to use because to use 0.5mm meshes causes a calculation problem and also there is a memory, numerous element necessity. Analyze results of 1mm size finite element network's consistency is given at Figure-6.

DISCUSSION:

Wood-Jones determined cervical fracture-dislocation mechanism firstly in 1913 (14). Garber coined the term of 'Axis Traumatic Spondylolisthesis' firstly in 1964 (4). Schneider used the term of 'Hangman's fracture' firstly (10). Hangman's fracture is a second cervical vertebra fracture that separates the anterior and the posterior elements of the vertebra. Fracture is either at the anterior side of the lateral masses or at the pedicle area of the vertebra (2,13).

In nominal profit and car accident traumas all weight, mostly affects pars interarticularis. Since the bone section is too small, this region is the weakest and the most sensitive region to the assumptions of the hangman (3).

According to literature, cadaveric and mathematical methods are the common methods in cervical biomechanical experiments. Human cadaveric models have the geometric and structural advantages. In vitro experimental results are the most acceptable results in biomechanical approaches. These models can be developed with surgical technique. Biologic variations, differences and expenditures are the limitations of this model. To form a statistically modeling, it is necessary to have numerous samplings (15). Spinal analytic studies, mathematical models can be classi-

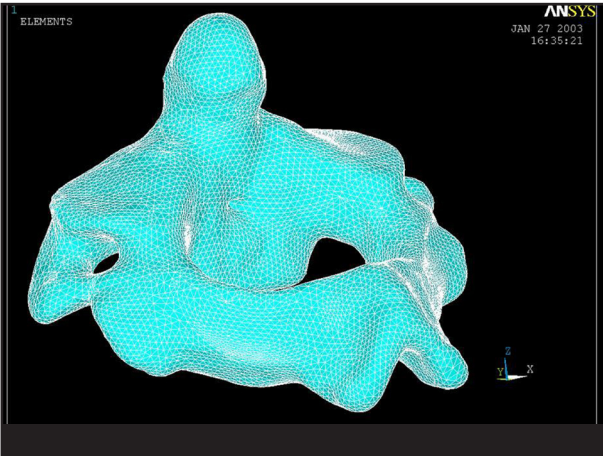


Figure-6. Comparative views of Finite element networks generated by 1.0 mm elements.

fied according to the geometry of the used model, applied force, analysis and application. Geometry of the model can be a complete system (Example: Colon, Complete cervical) or only a part of the system (Example; functional spinal unit). The force can be statistic loading by ignoring the time and the velocity or it can be a dynamic loading at a certain time and at a certain velocity. The mechanical analysis of material can be done as a linear analysis with a previously known geometry, deformation, and limitation and loading conditions or by changing these conditions; it can be done as a non-linear analysis. Mathematical models can be discussed as, according to learn the strength of the material or according to mechanisms of the traumas that has been observed in clinics. Computer simulation model generates from a group of mathematical equations related with the physical and geometric properties of the figurative structure.

The most common mathematical model for cervical vertebra is finite element method. Kinematic (intervertebral motions), mechanic (motion as an effect to the applied force), internal tensile and replacement can be the subjects of the study. Finite element method represents some ideal probabilities at checkpoints such as repeatability, changeability of any parameter, convertibility of quantity and quality of secondary effect on the diversity of certain parameter (1,8). Effects of instrumentation and surgical attempts during application of physiologic and traumatic loadings were studied. Determination of various anatomic elements can be discussed with this method (15). Using mathematical models in biomechanical area starts with 2D analysis by Orne and Liu in 1969; later on 3D models and then finite element method has been developed (9). In modern meaning 3D cervical vertebral anat-

omy was determined by defragmentation of 1mm periodic BT sections by Yoganannan et al, for the first time in 1996 (9,15).

A similar study to ours, aimed to determinate the atlas fractures mechanism has been done and by this way the most convenient results to the original ones have showed by Teo et al. in 2001 (11). Graham et al. (6) by this method examined the mechanism of odontoid process fractures and also had the most consistent results with the originals too.

In conclusion, results of our study supports the conventional experimental results of Teo's cadav-

eric study; thus, it has been observed that this study proves the accuracy of admittances in the analysis by quantitative method, limitation conditions, loadings and selected element types. Although nowadays nominal profit is vanished, there is a new factor of etiology of Hangman's fracture and it became a current issue because of air-bag accidents. Instead of using expensive cadaveric methods and methods of different quality, by using finite elements method, it would be possible to examine the trauma detailed and a high sensitivity.

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