ECRONICON OPEN ACCESS

EC DENTAL SCIENCE
Research Article

Comparison Between the Stresses Induced on Vital Structures During Two Steps and En-Masse Retraction Methods of Upper Anterior Segment Depending on Skeletal Anchorage System (FEM Study)

Ahmed Othman[1]*, Kareem Maher[2] and Wael Refai[3]

[1]MSc Orthodontic, Vienna, Austria

[2]Lecturer of Orthodontics in Minia University in Egypt

[3]Professor of Orthodontics in Minia University in Egypt

***Corresponding Author:** Ahmed Othman, MSc Orthodontic, Vienna, Austria.*

Received: April 04, 2017; **Published:** May 30, 2017

Abstract

FEM is considered as a method which greatly served the Orthodontic field as a powerful research tool for solving various structural mechanical problems. Many methods of stress analysis were introduced: strain gauge, photoelastic, or laser holographic techniques. The FEM was introduced into dental biomechanical research in 1973 [1] and since then had been applied to analyze the stress and strain fields in the alveolar support structures [2]. This was done by selecting the analytical model followed by CT scanning of the model and assembly of the 3D model components after that defining the model components, load and fixture. Meshing and collection of results were obtained, the stresses at the vital structures were calculated. The results were collected and a correlation analysis was performed. The results have shown that, stresses produced from using two step retractions were of insignificant comparing to stresses produced from en-masse retraction.

Keywords: *Stresses Induced; En-Masse Retraction Methods; Skeletal Anchorage System*

Introduction

There had been controversies concerning how to achieve maximum anchorage in the first premolar extraction cases.

Some researches informed that two step retraction is better than en-masse retraction as Proffit and Fields [3] while Roth [4] recommended for maximum anchorage extraction cases, other researchers also illustrated the anchorage during en-masse and two step retraction [5-11].

The introduction of skeletal anchorage devices was advantageous in Orthodontic treatment. The use of mini-screws not only facilitated the movement but also decreased anchorage loss. Accordingly, en-masse retraction can be done easily which will shorten the treatment duration.

FEM is recognized as a general procedure for mechanical approximation to all physical problems that can be modeled by differential equation description. Basically, FEM represents a mathematical modeling strategy of the load upon an object. Accordingly, the amount of stresses as well as the areas of stress concentration can be calculated.

The difference between 2 steps and en-masse retraction in terms of the stress induced in bone and teeth appeared to be a point of worthy investigation; the study was carried out to highlight this point.

The aim of the study was to compare between the stresses induced on vital structures during two steps and en-masse retraction methods of upper anterior segment depending on skeletal anchorage system (FEM study).

Materials and Methods

The current finite element analysis, designed in this study, simulates a clinical situation; upper anterior segment retraction by en-masse (Figure 1) or by two step retraction methods (Figure 2).

Figure 1: *En-masse retraction.*

Figure 2: *Two step retraction.*

The computer simulation of the suggested clinical situations utilized the following

1. Laptop computer with Intel ® Core (TM) I5-4210U, CPU @ 1.70GHz 2.40GHz, 6.00 GB of RAM, 64-bit Operating System, x64-based processor.
2. Materialize software (MIMICS 10.01 for Intel x86 platform v.10.2.1.2).
3. Solidworks 2015 x64 Edition, which is a finite element analysis and the 3D analysis program.
4. Windows 8.1 Pro (2013 Microsoft corporation).
5. Analytical model, developed from a human skull, taken from Faculty of medicine, Minia University, Egypt. The analytical model selected was juvenile dried skull. This was according to the strategy suggested by Gautam [12] to simulate the real age of case and the ideal bone density.

Figure 3.

Figure 4.

Figure 5.

Figure 6.

The CT scan images were exported to MIMICS program (Materialise Interactive Medical Image Control System).

Two operations were performed by this program

Cropping of CT scan images

- Selecting the desired structures of craniomaxillary complex from the whole skull images was performed by the following steps:
- Import the files of CT scan images.
- Select the sagittal cuts to crop.
- Threshold all hard tissue components of the CT images.
- Editing the masked images by circular eraser and deleting all structures other than the target structures.

Exporting the CT scan images

- The cropped files were saved as JPG extension files by.
- Standardize the cropped images by adjusting the X and Y axis of each image.
- Save/print screen shots of all processed images to gain 30 photos of 5 mm interval.

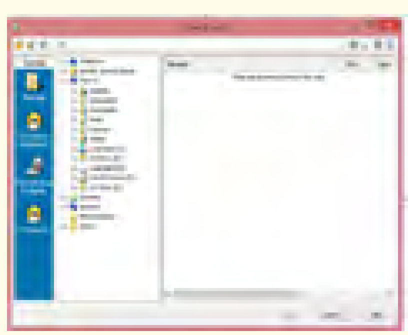

Figure 7.

Figure 8.

The main model

- Construction of the model was done on six steps [13] the first step was to divide the continuum or solution region into elements. A variety of element shapes may be used, and different element shapes may be employed in the same solution region. Although the number and the type of elements in each problem are matters of engineering judgment, the analyst can rely on the experience of others for guidelines.
- Practically, FEA usually consisted of three principal steps [14]. First is the Pre-processing, second is the Analysis and the third and last step is the Post-processing.
- The body of one half of the main maxillary model was constructed by dividing it into two parts, maxilla and orbital floor in one part, zygomatic bone and zygomatic arch in the other part.
- The body of the first part was constructed by drawing 31 2D sketches, drawn on the frontal plane (Figure 9).

Figure 9.

- Every 2D sketch was drawn in a separate plane.
- The distance between every plane and the other one was 5 mm interval (Figure 10).

Figure 10.

- Every 2D sketch was drawn by tracing the imported picture exported from Materialize Mimics (Figure 11).

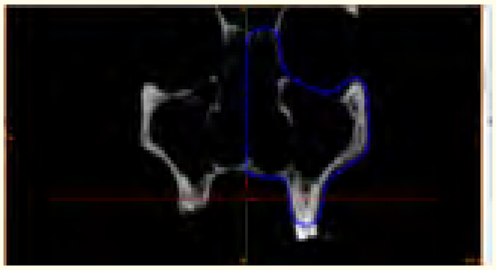

Figure 11.

- The body of the other part was constructed by the same way as the first part.
- The drawn sketches were joined together with the loft property to create a 3D model of one half of the basic maxillary body and zygoma (Figure 12, 13).

Figure 12.

Figure 13.

- Maxillary sinus and nasal cavity were drawn by lofted-cut property of the model (Figure 14).

Figure 14.

- Split feature was done on the right plane before mirror image (Figure 15).

Figure 15.

- The opposite half was generated by mirror imaging of the first half through the right plane to acquire the final model (Figure 16).

Figure 16.

Permanent dentition drawing

- Drawing of permanent teeth was based on the anatomical landmarks of every tooth.
- Root length, cervical line width, anatomical crown length and outline geometry of every tooth were considered.
- Drawing the root of every tooth was done by drawing a circle of the same radius as the radius of mid-root.
- Extrusion of the circle to the same length of root length was done to simulate the whole root length.
- Fillet one end of root to simulate the apical portion the natural root

- On the top plane, the cervical areas was drawn by drawing the cervical coronal cut of the natural tooth and loft it to the cervical portion of the simulated root.
- Four coronal cuts of the anatomical crown were drawn in a two dimensional manner from the cervical area to the incisal portion.
- The all four 2D sketches were lofted together to form of the anatomical crown of certain tooth.
- The occlusal surface of each tooth were constructed according to anatomical outline of such tooth (Incisal edge for incisors and canine or occlusal surface for premolar and molars)
- Two cusps were drawn on the occlusal surface of the premolar to simulate the natural occlusal surface and four cusps were drawn on the occlusal surface of the 1st molars in pyramidal-like geometry.

	Crown length	Root length	Crown MD	Diameter FL
Maxillary teeth				
Central incisor	10.5	13.0	8.5	7.0
Lateral incisor	9.0	13.0	6.5	6.0
Canine	10.0	17	7.5	8.0
1st premolar	8.5	14.0	7.0	9.0
2nd premolar	8.	14.0	7.0	9.0
First molar	7.5	B 12, L13	10.0	11.0

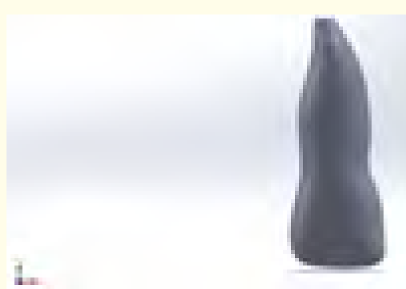

Figure 17: *Upper right Central Incisor.*

Figure 18: *Upper right lateral incisor.*

Figure 19: *Upper right canine.*

Figure 20: *Upper right canine.*

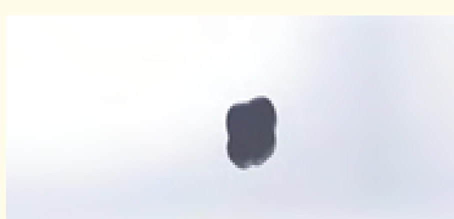

Figure 21: *Upper right 1st molar.*

Drawing of the titanium mini-screw

- Drawing of the screw was started by drawing of sagittal sketch of the screw according to anatomical dimension of the screw.
- Revolve was done to the sketch around the midline to form the general outline of the screw.
- Serration of the screw was drawn by forming helix and spiral curve along the length of the screw.
- Swept cut was done to the pitch element along the helix curve to form the serration of the screw.
- These steps were repeated to draw both screws.

Figure 22: *Mini-implant feature.*

Assembly of the three-dimensional components

- The constructed components were assembled together to form the two models assemblies.
- The technique of model assembly depends on the mating function presented in the assembly mode in solid work program software.
- The mating function created one or more geometrical relationship between different components.
- The mates used in this model were coincident and parallel.
- Coincident mates allow coincidence between two edges or surfaces.
- Parallel mate provide parallism between two linear edges or flat surfaces.
- The mating was accomplished between:
- Mating the teeth and the maxilla
- Mating the screw with the maxilla
- Mating the teeth and the PDL.

Tooth	1st	2nd	3rd	4th	5th	6th
Angulations	+5	+8	+10	0	0	0
Tooth	1st	2nd	3rd	4th	5th	6th
Angulations	+14	+7	-3	-7	-7	-10

Defining material properties for each component

- All materials in the study were considered to be homogenous, isotropic and linearly elastic.

- The modulus of elasticity and poison's ratio for the different component materials used in the study are listed in the (Table 3).
- Defining contacts and gaps between components.
- Defining model fixture and restrain for each model.
- Defining load applied on each model.
- Meshing the model.

Material name	Modulus of elasticity (Mpa)	Poison's ratio	Mass Density (kg/m^3)	Yield Strength (Mpa)
Spongy bone	13700	0.3	1900	170
Teeth	22000	0.3	1020	371.6
Titanium mini screw	117000	0.33	4428.78	750

Meshing the model

Model no.	Number of nodes	Number of element
Model A (Canine Retraction)	164232	113838
Model B (En-masse Retraction)	171354	118968
Model C (Incisor Retraction)	174796	121658

Running the analysis

Running of the two models took the following steps

- Forming surface to surface bonding.
- Establishing stiffness matrix.
- Preconditioning.
- Establish nodal force balance.
- Stress calculation.

Collection of results

- As the analysis was finished the result tree was activated. For stress calculation the von Mises stress was calculated at the elements in Mega Pascal (Mpa).
- The "list selected" property was used to calculate the average stress value for the elements.
- Results of interest were
    - Stress.
    - Factor of safety.
    - Displacement.
    - Strain.

Results

- Every area of measurement was represented by 10 points distributed equally in this area.

- All stress values were measured in Mega Pascal (Mpa) unit.
- Wilcoxon Signed Ranks Test was calculated in every area of interest to perform valid statistical analysis.

Wilcoxon Signed Ranks Test values (N = 12) at nasal floor (Mpa) case 1 and case 2

Model	Mean ± SD	Sum of rank	Mean rank	z	P
Case 1 (Canine Retraction)	0.24 ± 0.20	169	14.1	1.09	0.01*
Case 2 (En-masse retraction)	0.09 ± 0.02	131	10.9		

Wilcoxon Signed Ranks Test values (N = 12) at orbital floor (Mpa) case 1 and case 2

Model	Mean ± SD	Sum of rank	Mean rank	z	P
Case 1 (Canine Retraction)	0.03 ± 0.02	161	13.4	0.6	0.5
Case 2 (En-masse retraction)	0.02 ± 0.01	138	11.5		

Wilcoxon Signed Ranks Test values (N = 6) at maxillary Tuberosity (Mpa) case 1 and case 2

Model	Mean ± SD	Sum of rank	Mean rank	z	P
Case 1 (Canine Retraction)	0.02 ± 0.01	47	7.8	1.2	0.2
Case 2 (En-masse retraction)	0.01 ± 0.007	31	5.1		

Wilcoxon Signed Ranks Test values (N = 10) at maxillary sinus (Mpa) case 1 and case 2

Model	Mean ± SD	Sum of rank	Mean rank	z	P
Case 1 (Canine Retraction)	0.07 ± 0.02	106	10.6	0.07	0.9
Case 2 (En-masse retraction)	0.07 ± 0.02	104	10.4		

Maxillary Sinus Stresses

Point#	Maxil Sinus Case# 1 (MPa)	Maxil Sinus Case# 2 (MPa)	Difference (MPa)	Difference %	Notes
1	0.069	0.047	0.023	33%	
2	0.047	0.067	0.020	-42%	
3	0.046	0.066	0.027	-42%	
4	0.059	0.067	0.034	-14%	
5	0.069	0.081	0.040	-18%	
6	0.096	0.098	0.039	-2%	
7	0.112	0.115	0.039	-3%	The nearst point to implant
8	0.096	0.107	0.035	-12%	
9	0.062	0.041	0.030	33%	
10	0.046	0.057	0.024	-24%	
Average	0.07	0.07	0.03	-9%	

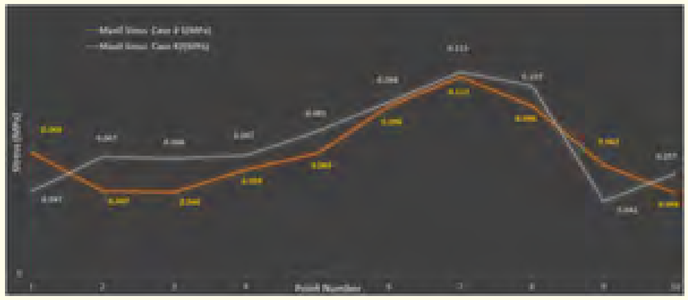

Figure 23.

Orbital Floor Stresses

Point#	Orbital Floor Case# 1 (MPa)	Orbital Floor Case# 2 (MPa)	Difference (MPa)	Difference %
1	0.020	0.065	0.023	-222%
2	0.026	0.075	0.020	-194%
3	0.022	0.068	0.027	-205%
4	0.018	0.082	0.034	-363%
5	0.030	0.076	0.040	-155%
6	0.051	0.074	0.039	-46%
7	0.066	0.081	0.039	-22%
8	0.064	0.090	0.035	-41%
9	0.056	0.102	0.030	-84%
10	0.047	0.106	0.024	-128%
11	0.023	0.108	0.012	-378%
12	0.004	0.001	0.001	65%
Average	0.04	0.08	0.03	-148%

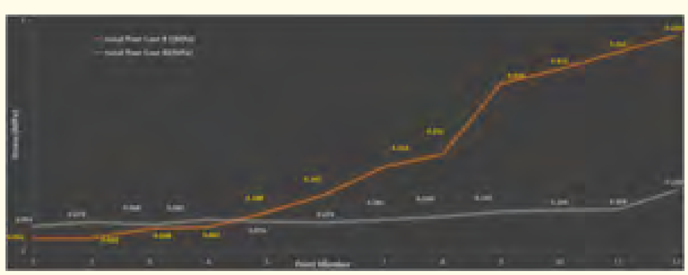

Figure 24.

Nasal Floor Stresses

Point#	Nasal Floor Case# 1 (MPa)	Nasal Floor Case# 2 (MPa)	Difference (MPa)	Difference %
1	0.032	0.065	-0.0334	-106%
2	0.033	0.075	-0.0416	-125%
3	0.058	0.068	-0.01	-17%
4	0.062	0.082	-0.0199	-32%
5	0.100	0.076	0.0237	24%
6	0.147	0.074	0.0728	50%
7	0.218	0.081	0.1372	63%
8	0.251	0.090	0.1611	64%
9	0.435	0.102	0.333	77%
10	0.472	0.106	0.366	78%
11	0.516	0.108	0.408	79%
12	0.559	0.158	0.401	72%
Average	0.24	0.08	0.15	19%

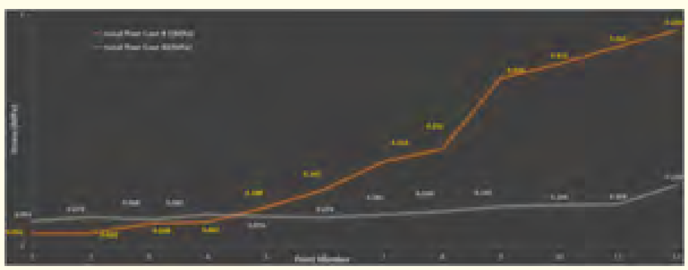

Figure 25.

Maxillary Tuberosity Stresses

Point#	Maxillary Tuberosity Case# 1 (MPa)	Maxillary Tuberosity Case# 2 (MPa)	Difference (MPa)	Difference %
1	0.037	0.022	0.023	40%
2	0.028	0.018	0.020	37%
3	0.010	0.012	0.027	-12%
4	0.020	0.007	0.034	73%
5	0.006	0.004	0.040	41%
6	0.010	0.003	0.039	67%
Average	0.02	0.01	0.0	41%

Max. Nasal Floor Stress (MPa)	0.559	Model 1 (Canine Retraction)
	0.158	Model 2 (En-masse Retraction)
Max. Orbital Floor Stress (MPa)	0.066	Model 1 (Canine Retraction)
	0.108	Model 2 (En-masse Retraction)
Max. Maxil Sinus Stress (MPa)	0.112	Model 1 (Canine Retraction)
	0.115	Model 2 (En-masse Retraction)
Max. Maxillary Tuberosity stress (MPa)	0.037	Model 1 (Canine Retraction)
	0.022	Model 2 (En-masse Retraction)

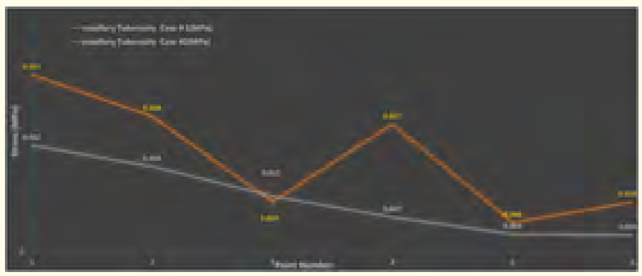

Figure 26.

Discussion

If a body is subjected to a tensile stress in the X-direction, then Poisson's Ratio is defined as the ratio of lateral contraction in the Y-direction divided by the longitudinal strain in the X-direction. Poisson's ratios in all planes are equal [14]. The magnitude of load applied when activating the retraction mechanics was 150 N [15] bilaterally. Maxillary Sinus average stress between case1 and case 2 has almost equal difference ranging between 0.023 and 0.04 Mpa; equal to 9% which proofs that the maximum stress point difference between case 1and 2 is only 3%. Nasal floor average stress of case 2 is less than average stress of case 1 by 1/3; maximum stress of case 1 is 3 times the maximum stress of case 2 and the difference is almost 73%. Maxillary tuberosity average stress of case 2 is almost half average stress of case 1; maximum stress of case 2 is less than case1 by 40%. Therefore: Case 2 is better than case 1. Orbital floor average stress in case 1 is half case 2 which therefore means that case 1 better than case 2.

Conclusion

1. Using two step retractions or en-masse retraction is possible, but the selected method should be accompanied by adequate amount of forces.
2. Increasing relaxation time between the activation of retraction is necessary to achieve bone stress relaxation.

Bibliography

1. Farah JW., *et al*. "Photoelastic and finite element stress analysis of a restored axisymmetric first molar". *Journal of Biomechanics* 6.5 (1973): 511-520.
2. Cobo J., *et al*. "Initial stress induced in periodontal tissue with diverse degrees of bone loss by an orthodontic force: Tridimensional analysis by means of the finite element method". *American Journal of Orthodontics and Dentofacial Orthopedics* 104.5 (1993): 448-454.
3. Proffit WR and Fields HW Jr. "Contemporary orthodontics. 3rd ed". St Louis, Mo: CV Mosby, (2000): 348.
4. Roth RH. "Treatment mechanics for the straight wire appliance". In: Graber TM, Vanarssall RL (eds). Orthodontics, Current Principles and Techniques. 2nd ed. St Louis, Mo: CV Mosby, (1994): 685-711.
5. Tweed CH. "The application of the principles of the edgewise arch in the treatment of malocclusions". *Angle Orthodontist* 9 (1941): 12-67.
6. Tweed CH and Tucson A. "A philosophy of orthodontic treatment". *American Journal of Orthodontics and Oral Surgery* 31.2 (1945): 74-103.
7. Tweed CH. "Clinical Orthodontics". St Louis, MO: CV Mosby (1966): 248-68.
8. Storey E and Smith R. "Force in orthodontics and its relation to tooth movement". *Australian Dental Journal* 56 (1952): 13.
9. Begg PR. "Differential force in orthodontic treatment". *American Journal of Orthodontics* 42.7 (1956): 481-510.
10. Staggers JA and Germane N. "Clinical considerations in the use of retraction mechanics". *Journal of Clinical Orthodontics* 25.6 (1991): 364-369.
11. Burstone C. "Anchorage control and the extraction patient". In: Sachdeva RCL, Bantleon HP, White L, Johnson J (eds). Orthod for the Next Millennium. Glendora, Calif: Ormco (2001): 293.
12. Gautam P., *et al*. "Stress and displacement patterns in the craniofacial skeleton with rapid maxillary expansion: A finite element method study". *American Journal of Orthodontics and Dentofacial Orthopedic* 132.1 (2007): 5.e1-5.e11.
13. Clough RW. "The finite element method after twenty-five years: A personal view". *Computers and Structures* 12 (1980): 361-370.
14. Wiley J. "Concepts and applications of finite element analysis" (1989).
15. Von Fraunhofer JA., *et al*. "Force generation by orthodontic coil springs". *Angle Orthodontist* 63.2 (1993): 145-148.

Volume 11 Issue 1 May 2017