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Effect of light continuous force on the mid palatal suture

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ABSTRACT: The aim of this study was to quantify the amount of maxillary expansion occurring at the mid palatal suture after applying light and continuous forces, studied by the means of finite element analysis. For creating the finite element models, cone-beam computed tomography (CBCT) scanswere used to first create stereolithographic models, and then further converted into three finite element models. Force levels between 5-15cN were obtained by simulating copper-nickel titanium (Cu-NiTi) archwires of diameter 0.014”, 0.016” and 0.018” as measured by the finite element analysis. The wire was placed on the palatal aspect of the maxillary teeth to give a buccally directed light, continuous force. The effects of this force were studied by measuring the amount of expansion occurring at the mid palatal suture, as well as the stress distribution and the displacement patterns at the mid palatal suture and in the buccal periodontium of maxillary first molars. Results indicated that the mid-palatal suture showed stress distribution and displacement in a similar pattern as seen in previous studies with heavier forces. The effects on the buccal periodontium showed an even distribution of the stresses along the root length, thus suggesting that fenestration which is caused due to concentration of heavy forces can be avoided with the lighter forces. Clinical studies are indicated to further validate this approach for palatal expansion, and to determine the lowest force capable of causing mid palatal suture opening without having any deleterious effects on the buccal periodontium of anchor teeth.

KEYWORDS: Maxillary expansion, FEM, light forces, mid palatal suture, buccal periodontium.

I. INTRODUCTION

Maxillary expansion has been an established treatment modality in Orthodontics, which is attributed to changes in the mid-palatal suture and/or remodelling of the dentoalveolar process. But orthodontic correction of maxillary constriction can be deemed to be challenging since facial growth in the transverse dimension decreases during late childhood.[1] Methods of maxillary expansion are broadly categorized as slow and rapid maxillary expansion based on the rate of force application. Additionally, the force exerted by rapid maxillary expansion (RME) appliances may often be as high as 15–50 N, producing deleterious side effects on the mid-palatal suture and can contribute to root resorption.[2,3] Thus, light and continuous forces can serve as an alternative to such heavy forces. The equilibrium theory of tooth position concludes that pressure applied on the dentition by the perioral musculature is as low as 1-2 grams (1-2 Centi Newtons) [4,5], and it is adequate to cause tooth movement. Consequently, an animal study has shown sutural response after application of light, continuous forces on the maxilla, and proposed the need for further research to analyse the biomechanical effects and is suggestive of need for clinical trials with the use of such forces.[6]

This study has given an insight on the biomechanical effects of light continuous forces on the mid-palatal suture by the means of a copper-nickel- titanium (Cu- NiTi) arch wire placed on the palatal surfaces of the maxillary teeth, as simulated on a finite element model. The results obtained from this study may serve as a guide in the clinical use of this technique according to the stresses generated on the mid palatal suture and other periodontal tissues to expand the maxilla.

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II. MATERIALS AND METHODS

3 cone-beam computed tomography (CBCT) scans of patients between the age groups 11-15 years, 16-20 years and 21-25 years respectively were taken from Dashabhuja CBCT Centre, Pune. For creating the computer-aided design (CAD) models, the CBCT scans were converted into stereolithography (STL) format files. After the CAD models were generated, they were converted into finite element models (FEM) with meshing of tetrahedron elements, and the Cu-NiTi arch wire was modelled similarly and attached to the teeth palatally (Figure 1). No labial appliances were placed in this study.

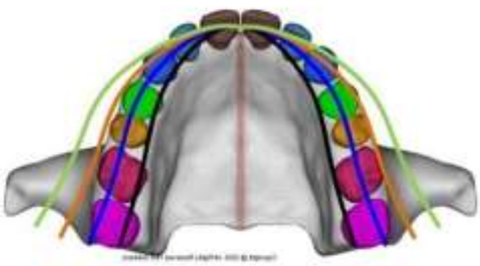

Figure 1. Simulated model of the maxilla with the archwires to apply buccally directed forces with activation of 2mm.

The total numbers of elements and nodes required in the geometry of the model have been enlisted in Table 1. The mechanical properties of the tooth, cortical bone, cancellous bone, suture, periodontal ligament, and nickel titanium in the model were defined according to the experimental data in previous studies[7,8] as shown in Table 2. The nodes of the mid-palatal suture element that were created in this study were placed on a symmetrical plane and were left unconstrained. The 3-dimensional coordinates were X, transverse plane; Y, sagittal plane; and Z, vertical plane.

Table 1: Node and element count for the FEM model.

COMPONENT	NO. OF NODES	NO. OF ELEMENTS
Teeth	119469	559395
Periodontal Ligament (Pdl)	123700	195488
Jaw Bone (Cortical and cancellous)	129036	638533
Mid-Palatal Suture	22761	99906
Cu-Niti Arch Wire 0.014"	18942	14752
Cu-Niti Arch Wire 0.016"	26334	22128
Cu-Niti Arch Wire 0.018"	33726	29504

Table 2: Material properties data representation.[7,8]

	YOUNG'S MODULUS (N/mm^2)	POISSON'S RATIO
Tooth	2.07×10^4	0.30
Compact bone	1.37×10^4	0.30
Cancellous bone	7.9×10^3	0.30
Periodontal ligament	50	0.49
Mid-palatal suture	7	0.40
Nickel titanium	44×10^3	0.33

The arch wire expansion appliance was then simulated on the models using a 0.014- inch, 0.016-inch and 0.018-inch copper-nickel-titanium (Cu-NiTi) pre-fabricated arch wires. Each arch wire was activated by 2mm, up to 6mm, in the molar region, such that the effects of expansion were studied for each of the three wire sizes per 2mm activation on all the three models.

The stress distribution and the displacement patterns in the mid-palatal suture and at the level of the maxillary first permanent molar were studied at specified points A, B, C and D for each of the design variables. Point A was taken as a point near incisive foramen, point D was taken as a point near palatine bone, whereas Points B and C were taken such that they divided the A–D line into three equal parts (Figure 2).

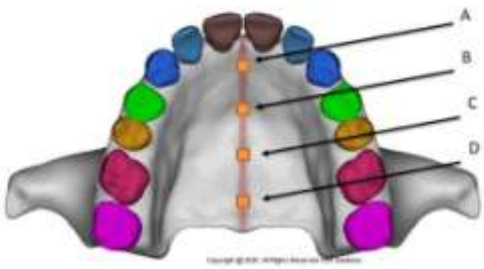

Figure 2. Predetermined points on the mid palatal suture.

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The stress distribution on the buccal periodontium of the first molar was also assessed to study the effects of the expansion forces on the teeth and supporting structures. This was evaluated at three predetermined points along the long axis of the first molar. These points were taken as perpendicular distances from the cementoenamel junction (CEJ), the root apex of the palatal root and the mid root level of the palatal root on the long axis of the tooth (Figure 3). To evaluate the amount of suture opening, changes in inter molar distances were also evaluated. The inter molar distance was measured at four predetermined points. The fringe plots for all these measurements as obtained from the finite element processing software were compiled. The numerical results and cumulative data after the analysis have been discussed.

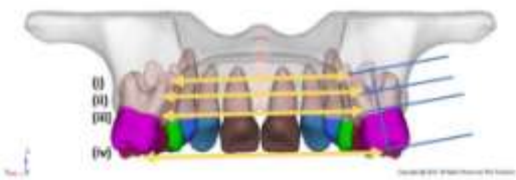


Figure 3. Predetermined points along the long axis of the maxillary first molar tooth to asses changes on the buccal periodontium.

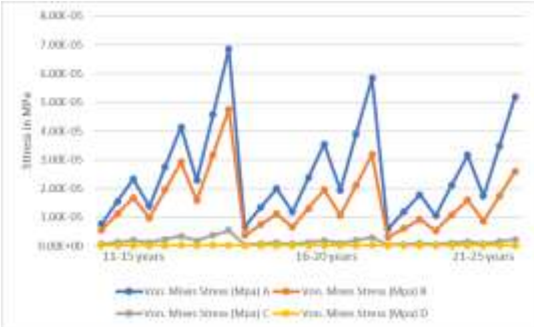
III. RESULTS

Finite element model data post-processing gives a fringe plot or a contour plot, shown to identify the nodes where the high stress regions are for a given load. These stresses are color coded, with the color red depicting the maximum values and blue depicting the lowest, showing the section of mid palatal suture in this study. Such fringe plots were obtained in this study of the section at the mid palatal suture, and at the buccal periodontium of the first molar tooth.

The results of this study are described under the stress distribution seen at the mid palatal suture and the buccal periodontium of the first molar tooth, and the displacement patterns at the mid palatal suture and as the change in the inter molar distance.

I. Stress distribution at the mid palatal suture:

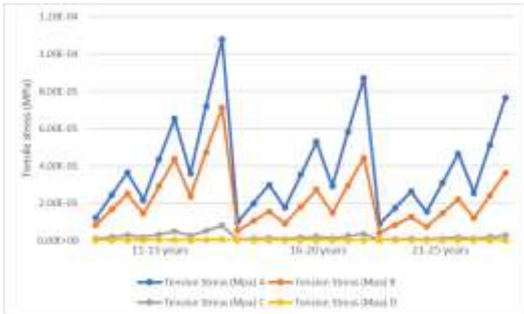
Stress patterns studied were those of Von Mises stresses and were also further differentiated into tensile and compressive principal stresses for evaluation of the results. The fringe plots obtained showed that the Von Mises stresses developed at the mid palatal suture were maximum at Point A and minimum at Point D. Compressive stresses and tensile stresses also showed the same pattern with maximum stresses at Point A and minimum at Point D. (Graph 1)



Graph 1. Von Mises stresses at the mid palatal suture.

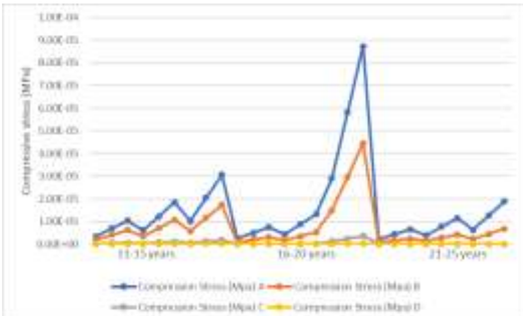
Within one age group, three peaks are observed in the graph, which represent the three different wire dimensions. Each wire further shows the millimetric activations.

Graph 2 depicts tensile stress distribution through all age groups with different wire sizes and their activations. The highest peak is observed at Point A in the 11-15 years age group model, which depicts the 0.018” wire dimension with 6mm activation.



Graph 2. Tensile stresses at the mid palatal suture.

Graph 3 depicts compressive stresses, with the youngest age group of 11-15 years showing the highest stresses amongst all the age groups and wire dimensions.



Graph 3. Compressive stresses at the mid palatal suture.

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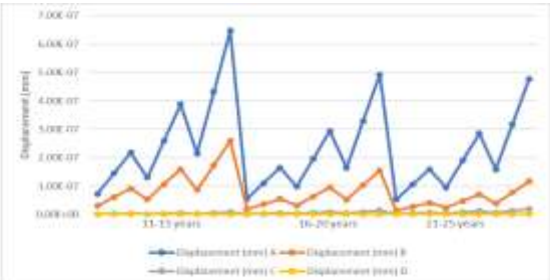
II. Displacement patterns at the mid palatal suture:

The displacement patterns along the mid palatal suture were also studied in the same fringe plot format. A similar pattern to the stress distribution, showing more amount of displacement anteriorly and with greater wire activation was observed. It was seen that within one age group, there was more displacement with increasing wire dimension and its activations.

III. Stress distribution in the buccal periodontium of the maxillary first molar tooth:

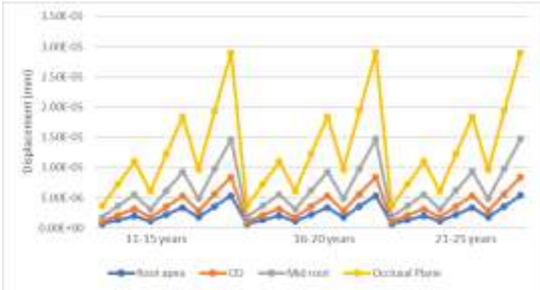
The periodontium corresponding to the predetermined points at the root apex, mid root level and at the CEJ was assessed. Results showed that the stresses were equivalent at the root apex and the cementoenamel junction (CEJ). This suggests that there was uniform stress distribution all over the root surface. Higher stresses were observed with larger wire dimensions and larger activations. (Graph 4)



Graph 4. Stresses at the buccal periodontium of the maxillary first molar tooth.

IV. Displacement of the maxillary first molar tooth:

Displacement occurring secondary to the expansion forces served as a measure of change in the intermolar distance to evaluate the effect of suture opening on the dentition. The intermolar distance was also calculated at three other points to evaluate the nature of tooth movement, whether the forces are concentrated at one point or evenly distributed. The tooth displacement observed was of nearly the same amount at all the four predetermined points on the long axis of the first molar, thus suggesting that the forces were not concentrated at a single point. This numerical data has been graphically presented to analyse the nature of tooth movement in Graph 5.



Graph 5. Displacement patterns at the buccal periodontium of the maxillary first molar tooth.

IV. DISCUSSION

There have been concerns about moving the roots of teeth through the buccal cortical plate of bone, referred to as fenestration and dehiscence, involving periodontal deterioration with most of the methods of rapid maxillary expansion. This is determined by the amount of forces used, whether they are orthodontic or orthopaedic in nature. Other factors which govern the effects of expansion are the individual's gender, age, growth potential, thus making it unpredictable.

It has been reported that, during rapid maxillary expansion, forces between 13N and 45N (3-10 pounds) are produced by single activation of jackscrew appliances, while multiple daily activations could result in cumulative loads of 90N (20 pounds) or more.[9,10] Such high forces have damaging and undesirable effects on the periodontal tissues. Teeth serving as anchors for the expansion appliance were extracted from humans and animals for subsequent histological examination, have also shown root resorption.[2,11-13] On the contrary, slow maxillary expansion appliances such as the Quad -helix or the Minne-expander result in loads varying from a few ounces up to approximately 2 pounds.[2,3]

Recently, the results from an animal study indicated that maxillary expansion with light, continuous force is a viable alternative to RME with heavy, interrupted forces because the molars maintained healthy periodontal support as the alveolar process was expanded.[6] Considering this, the force levels for the current study were ranging from 1.9cN to 16.2cN (1.94g to 16.31g) as found by simulating Cu-Niti archwires placed palatally on the maxillary teeth, which delivered buccally directed forces. Such low force levels were possible by simulating the copper NiTi (Cu-NiTi) alloy, as compared to the forces generated by the stainless steel alloy which is conventionally used in other expansion devices. For very small

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activations, Cu-Niti generates near constant forces, thus, 2mm activations up to 6mm were simulated on each arch wire of diameters 0.014”, 0.016” and 0.018”. The gradual rate of expansion maintains tissue integrity and elicits a physiologic response that allows bone deposition along the suture to keep pace.[9,14]

Our evaluation in all the three age groups showed that maximum stresses were observed with a 6mm activation for each wire which delivered forces between 5.9cN to 16.18cN. The stresses along the mid palatal suture in all age groups increased from the posterior to the anterior. These patterns of stress distribution were similar to those observed in a FEM study comparing Quad helix and NiTi expander appliances.[15] The V- shaped opening of the midline suture in this study was evident, similar to the results from the previous studies which reported that the separations were more in the anterior region than in the posterior due to the buttressing effect of the zygomatic bone and other surrounding craniofacial structures, and the pattern of fusion of the mid palatal suture beginning posteriorly.[16-21]

The model constructed for the age group 11-15 years showed a patent and the widest suture among all the three groups. Maximum displacement of the suturalelements was observed in this age group, which can be attributed to the initial width of the suture. Collectively, these findings correlate to the clinical outcomes of maxillary expansion in children and adolescents,[22-25] but displacement as low as 1.02x10-5mm at the sutural elements is clinically insignificant. In the age group 15- 20 years, a similar trend was seen, with the stresses being greatest at Point A, dropping lower at point B, and then increasing at Points C and D. Overall stresses were greater than that in the younger age group model. This can be correlated to increased interdigitation of the mid palatal suture and reduced width, frequently observed in individuals of this age group as compared to the younger individuals.[22] A similar trend of stress distribution was observed in a finite element model constructed with a fused mid palatal suture which concluded that because the expansion force was placed from the lingual aspect of the first molars, high concentrations of tension stress were seen especially at the junction of the palatine bone and the pterygoid plate structure. This represents a high tensile stress resistant to the separation of the maxillary bones.[26] Although other circum-maxillary bones and sutures were not simulated in this study, the boundary conditions and degrees of freedom was restrained in a comparable manner. Greatest amounts of stresses were observed in the oldest age group of 21-25 years. This finding is in accordance with the fact that increase of interdigitation in the mid palatal suture causes a decrease in response to skeletal expansion especially after puberty.[22,27]

To assess the dental versus skeletal effects of these forces, the displacement of the first molars at the level of occlusal plane was measured. This was reflected in the results as the displacement obtained in the X axis, and can be clinically correlated to the intermolar distance. The amount of change seen in the inter molar distance before and after application of expansion forces showed a typical trend ofprogressively increasing with increase in activations from 2mm to 6mm of the wires. The same trend was observed in all the three age groups in the numerical values of the change of intermolar distance, being the same in all groups. Since the amount of change is not significant clinically, and we may conclude that there are no dental effects of expansion with such low forces. Further application of this prospect stands questionable as it would be beneficial to correct crowding in the dental units in the initial stages of treatment at the cost of expansion of the dental arch.

Effects on the buccal periodontium of the first molar teeth were studied by evaluating stresses generated on the periodontal tissues corresponding to mesiobuccal root apex, mid root level of the mesio-buccal root and two points buccally on the cementoenamel junction (CEJ).[6] Greater stresses were observed with the 6mm activation in 0.018” wire, but the range of the stresses was the same in all the three age groups. There was a steeper rise in the stresses with increase in the activation of the wire groups.

The limitations of this study involve several approximations in the material properties of the tissues. Variations of trabecular and alveolar bone, teeth, enamel, dentin, and pulp were not considered. Our FEM models did not include the whole skull, and the boundary condition was not fixed at the foramen magnum, so the result represents only the response of part of the craniofacial structure. Elements representing tissues were considered isotropic and solved with linear-elastic properties. Because only the mid palatal suture was included in the FE models, the result might not represent the true clinical condition, since the rest of the craniofacial sutures were not considered. The FE models in this study were based on three individuals’ anatomy, and the results should be interpreted accordingly. Therefore, individual characteristics such as the maxilla's position relative to the cranial base, incisor positions, arch forms,and dental inclinations may vary person to person. Also, the tissue remodelling attempted to simulate in this study is an approximation of the clinical situation. Tissue response and remodelling varies individual to individual with factors like age, gender, and systemic conditions playing an important role.

V. CONCLUSION

Overall, the results from this study indicate that maxillary expansion with light, continuous force could be a feasible alternative to RME which generates heavy, interrupted forces since the mid palatal suture showed some displacement in the transverse direction, and the molars maintained a healthy periodontium and showed bodily movement.

Clinical significance: Detailed clinical studies are indicated to further validate this approach for palatal expansion to determine a clinically significant lowest force capable of causing mid palatal suture opening without having any deleterious effects on the buccal periodontium of anchor teeth. By achieving this, heavy forces and its effects can be avoided.

REFERENCES

[1]. Goldstein MS. Changes in dimensions and form of the face and head with age. Am J Phys Anthropol 1936;22:37-89.
[2]. Langford SR, Sims MR. Root surface resorption, repair, and periodontal attachment following rapid maxillary expansion in man. Am J Orthod 1982;81:108– 115.
[3]. Linder-Aronson S, Lindgren J. The skeletal and dental effects of rapid maxillary expansion. Br J Orthod 1979;6:25–29.
[4]. Weinstein S, Haack DC, Morris LY, Snyder BB, Attaway HE. On an equilibrium theory of tooth position. Angle Orthod 1963;33:1–26.
[5]. Proffit WR. Equilibrium theory revisited: factors influencing position of the teeth. Angle Orthod 1978;48:175–186.
[6]. Utreja A, Bain C, Turek B, Hollande R, AlRasheed R, Sorkhdini P, Roberts WE. Maxillary expansion in an animal model with light, continuous force. Angle Orthod 2018;88(3): 306-313.
[7]. Lee NK, Beak SH. Stress and displacement between maxillary protraction with miniplates placed at the infrazygomatic crest and the lateral nasal wall: A 3- dimensional finite element analysis. Am J Orthod Dentofac Orthop 2012;141:345–51.
[8]. IB, Charfi A, Bouraoui T, Elleuch K. Finite element modelling of superelastic nickel-titanium orthodontic wires. J Biomechanics 2014;47:3630–3638.
[9]. Isaacson RJ, Wood JL, Ingram AH. Forces produced by rapid maxillary expansion. Angle Orthod 1964; 34: 256-270.
[10]. Zimring JF, Isaacson RJ. Forces produced by rapid maxillary expansion. Angle Orthod 1965;35: 178-186.
[11]. Debbane EF. A cephalometric and histologic study of the effect of orthodontic expansion of the mid-palatal suture of the cat. Am J Orthod 1958; 44: 187-219.
[12]. Starnbach H, Bayne D, Cleall J, Subtelny JD. Facioskeletal and dental changes resulting from rapid maxillary expansion. Angle Orthod 1966; 36: 152-164.
[13]. Timms DJ, Moss JP. An histological evaluation into the effects of rapid maxillary expansion on the teeth and their supporting tissues. Trans Eur Orthod Soc 1971; pp. 263-271.
[14]. Storey E. Tissue response to the movement of bones. Am J Orthod 1973; 6:229-247
[15]. Kumar A, Ghafoor H, Khanam A. A comparison of three-dimensional stress distribution and displacement of nasomaxillary complex on application of forces using quad-helix and nickel titanium palatal expander 2 (NPE2): a FEM study. Progress in Orthodontics 2016;17:17.
[16]. Haas AJ. Rapid expansion of the maxillary dental arch and nasal cavity by opening the midpalatal suture. Angle Orthod 1961; 31: 73-90.
[17]. Wertz R, Dreskin M. Midpalatal suture opening: A normative study. Am J Orthod 1977; 71: 367-381.
[18]. Cleall JF, Bayne D, Posen J, Subtelny JD. Expansion of the midpalatal suture in the monkey. Angle Orthod 1965;35:23–35.
[19]. Davis WM, Kronman JH. Anatomical changes induced by splitting of the midpalatal suture. Angle Orthod 1969;39:126–132.
[20]. Memikoglu TUT, Iseri H. Effects of a bonded rapid maxillary expansion appliance during orthodontic treatment. Angle Orthod 1999;69:251–256.
[21]. Iseri H, Tekkaya AE, Oztan O, Bilgic S. Biomechanical effect of rapid maxillary expansion on the craniofacial skeleton,

International Journal Dental and Medical Sciences Research
Volume 4, Issue 2, Mar-Apr 2022 pp 83-89 www.ijdmsrjournal.com ISSN: 2582-6018

studied by the finite element method. Eur J Orthod 1998;20:347–356.
[22]. Persson M, Thilander B. Palatal suture closure in man from 15 to 35 years of age. Am J Orthod 1977;72:42-52.
[23]. Knaup B, Yildizhan F, Wehrbein H. Age-related changes in the mid palatal suture. J Orofac Orthop 2004;65:467-74.
[24]. Korbmacher H, Schilling A, Puschel K, Amling M, Kahl-Nieke B. Age-dependent three-dimensional micro-computed tomography analysis of the human midpalatal suture. J Orofac Orthop 2007;68:364-76.
[25]. Melsen B. Palatal growth studied on human autopsy material. A histologic microradiographic study. Am J Orthod 1975;68:42–54.
[26]. Eoma J, Bayomeb M, Park JH, Lim HJ, Kook YA, Hang SH. Displacement and stress distribution of the maxillofacial complex during maxillary protraction using palatal plates: A three-dimensional finite element analysis. Korean J Orthod 2018;48:304-315.

[27]. Handelman CS. Nonsurgical rapid maxillary alveolar expansion in adults: a clinical evaluation. Angle Orthod 1997;67(4):291–305.