Are Increased Masticatory Forces Risk for Primary 2nd Molars without Successors? A 3D FEA Study

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Objective: *Persistent primary teeth with healthy crown-root structures and acceptable functional and esthetic properties may be preserved over a long-term period if needed. However, they may experience root resorption, ankylosis or infraocclusion especially in the second or third decades of life. Despite a lack of sufficient detailed data, increases in occlusal forces by age are known to cause destructive stresses on root surfaces and periodontal tissue. The aim of this study was to evaluate the effect of increasing occlusal forces on mandibular persistent primary molars by using 3D finite element analysis.* ***Study Design:*** *The impact of increased masticatory forces on compressive and tensile stresses in tooth and surrounding tissue was simulated in two different models (simulating child and adult mouths) by using 3D finite element analysis.* ***Results:*** *In both models, the stress values increased by age and compressive stresses were seen on internal root surfaces, while the tensile stresses focused on the furcation area and external root surfaces.* ***Conclusion:*** *It was concluded that practices such as reducing occlusal surface width may be used to diminish the occlusal forces for long-term tooth survival in persistent primary molars.*

Key words: *Hypodontia, Stress Analysis, Computer Simulation, Biomechanics, Root Resorption, Ankylosis*

INTRODUCTION

Excluding third molars, tooth agenesis is most often seen in mandibular second premolars, with a prevalence rate between 2.5% and 5%.[1] Early diagnosis of congenital agenesis, especially during the early stages of mixed dentition, may offer more treatment options,[1,2] including less invasive options such as spontaneous closure of the space following extraction of the primary tooth.[2,3] In cases where primary second molars require extraction due to poor prognosis, the remaining space can either be closed in orthodontic treatment or saved for future autotransplantation, prosthetic appliances or dental implants.[1,2,4-6]

Persistent primary teeth with healthy crown-root structures and acceptable functional and esthetic properties may be retained as a long-term treatment option.[3] Teeth that are maintained for this purpose have been proven to be capable of surviving until the ages of 20-30 years.[6,7] However, persistent primary teeth may be affected by pathologies such as root resorption, ankylosis and infraocclusion, which may develop especially during pubertal growth.[6,8-10] While the etiological factors involved in these pathologies are unclear, a number of studies have asserted that increasing masticatory forces applied to primary teeth may initiate the process of root resorption.[11]

Under normal circumstances, primary molars serve in both primary and mixed dentition and are thus designed with wide occlusal surfaces and long roots that diverge to provide space for permanent tooth germs.[12] However, there is little information about how primary molars are affected by the greater occlusal forces present in permanent dentition. According to one study,[13] when primary teeth without permanent successors are subjected to overwhelming force, periodontal ligament (PDL) necrosis may occur, which may in turn induce local cytokine production. Once the PDL tissue is impaired, resorption processes begin. Moreover, irregularities in the resorptive and reparative processes of root resorption may cause ankylosis, which can result in infraocclusion.[8,9]

Different methods are available for evaluating the stresses arising from forces on dental tissue, including photoelastic analysis, strain-gauge analysis, brittle-lacquer stress analysis, thermographic

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stress analysis and finite element analysis (FEA).[14-16] FEA is a non-invasive technique that can provide an accurate, reliable three-dimensional picture of stress distribution under different loading circumstances. The structures to be examined are modeled to simulate anatomical conditions, a simulated load is then applied, and the results are analyzed.[14-16.]

The aim of this study was to analyze whether or not the increase in masticatory forces from childhood to adulthood provoke stresses in primary second molars and supporting tissue that can lead to pathological root resorption, ankylosis and infraocclusion in tooth and periodontal tissue of persistent mandibular primary second molars without permanent successors.

MATERIALS AND METHOD

A primary second molar tooth that was extracted during the treatment of a patient with congenital tooth agenesis was scanned using an Activity 880 3D scanning device (Smart Optics Sensorttechnik GmbH, Sinterstrasse 8, D-44795 Bochum, Germany) in order to obtain an accurate and realistic model. Rhinoceros 4.0 (3670 Woodland Park Ave N, Seattle, WA 98103 USA) and VRMesh Studio (VirtualGrid Inc, Bellevue City, WA, USA) 3-D modeling software were used to construct a mathematical model of this tooth in a child's mouth and in an adult mouth. Both models used the same anatomical data for enamel and dentine thickness and periodontal space width (Table 1), whereas cortical and cancellous bone thickness varied between the two models (Table 1). Modeling was completed with the addition of a periodontal ligament (PDL). Young's modulus and Poisson ratios for the dental and periodontal tissues that were used in the models are provided in Table 2. All structures were considered to be homogenous, isotropic and linearly elastic.

Once modeling was complete, a structure representing a semi-round solid item (i.e. foodstuff) in contact with the occlusal surface of the tooth was selected for applying force. In the first model, a force of 289.28 N was applied to represent the average force of a child who is 8.13 years of age according to the method by Owais *et al*,[17] and in the second model, a force of 601.83 N was applied to represent the average force of an adult who is aged 21.4 years, according to the method by Sathyanarayana and Premkumar.[18] Analysis was performed using the Algor Fempro software (ALGOR, Inc. 150 Beta Drive Pittsburgh, PA 15238-2932 USA). The first model that was used in the study was constructed with 1,086,611 elements and 195,584 nodes, while the second model contained 1,084,804 elements and 196,626 nodes. For both models, the minimum principle stress values (indicating compressive stress) and maximum principle stress values (indicating tensile stress) were calculated and evaluated numerically on specific tooth areas including the inner and outer surfaces of mesial and distal root, mesial and distal cervical areas and furcation. Additionally, in order to evaluate the stresses on dental and periodontal tissue more accurately, a color stress scale was used to visualize the minimum/maximum principle stresses for each tooth model.

RESULTS

The minimum principle stresses for both models were found to converge mainly on the middle third of the inner surface of the roots, with less stress on the coronal third of the external surface of the roots and even less in the furcation region. The minimum principle stress values were higher in the second model in comparison to the first model, especially around the middle third of the inner surface of the roots (Table 3 and Figure 1a,b).

The maximum principle stresses for both models were found to be the highest in the middle third of the external surface of the roots, especially in the furcation region, whereas the internal root surfaces were affected to a lesser extent. The maximum principle stress values were higher in the second model in comparison to the

Table 1: Tissue thicknesses of mandibular second primary molar and periodontal tissues.

	Mesial	Distal	Buccal	Lingual	Occlusal	Reference
Enamel Thickness	*0.76 mm.	*0.82 mm.	*0.933 mm.	*0.653 mm.	**0.785 mm.	*19 **20
Dentine Thickness	2.130 mm.	2.192 mm.	3.006 mm.	2.730 mm.	2.570 mm.	21
Periodontal space width			0.20 mm.			22
Cortical Bone Thickness		1st Model		2nd Model		
	Buccal	Lingual	Buccal	Lingual		23
	2.15 mm.	2.65 mm.	2.5 mm.	2.7 mm.		
Cancellous Bone Thickness		1st Model		2nd Model		23
	6.4 mm.			6.1 mm.		

Table 2: Young modulus and Poisson ratios of teeth and periodontal tissues.

Tissue	Young Modulus	Poisson Ratio	Reference
Enamel	80350	0.33	24
Dentin	19890	0.31	24
Pulp	2	0.45	25
Spongious Bone	490	0.30	26
Cortical Bone	14700	0.30	26
Periodontal Ligament	69	0.45	27

first model, especially in the external surface of the roots (Table 3 and Figure 1c,d).

The stress values in cancellous and cortical bone were lower than the stress values in tooth tissue. The minimum principle stresses on cancellous bone were found mainly at the tooth apex and furcation region, whereas in the cortical bone, they were distributed at around the cervical area of the tooth (Figure 2a,b). The maximum principle stresses on the cancellous bone were found to be mainly around the middle third of the root, whereas a more even distribution of stress was observed for the cortical bone (Figure 2c,d). Both the minimum and maximum stresses in the bone tissue were higher in model 2 in comparison to model 1 due to the increases in masticatory forces that emerge due to age.

Table 3: Minimum and maximum principle stress results for both models.

Tooth Surfaces	Minimum principle stresses for the 1st model (N/mm^2=MPa)	Maximum principle stresses for the 1nd model (N/mm^2=MPa)	Minimum principle stresses for the 2nd model (N/mm^2=MPa)	Maximum principle stresses for the 2nd model (N/mm^2=MPa)
Inner surface of mesial root	≈ -17.7 MPa	≈ -0.56 MPa	≈ -39.3 MPa	≈ -0.04 MPa
External surface of mesial root	≈ -13.9 MPa	≈ 3.08 MPa	≈ -23.4 MPa	≈ 7.2 MPa
Inner surface of distal root	≈ -17.6 MPa	≈ -1.09 MPa	≈ -35.9 MPa	≈ -1.8 MPa
External surface of distal root	≈ -11.8 MPa	≈ 1.88 MPa	≈ -12 MPa	≈ 6.94 MPa
Mesial cervical area	≈ -12.8 MPa	≈ 0.26 MPa	≈ -26.7 MPa	≈ 0.5 MPa
Distal cervical area	≈ -19.6 MPa	≈ -0.21 MPa	≈ -41 MPa	≈ -0.4 MPa
Furcation	≈ -5.6 MPa	≈ 8.99 MPa	≈ -10.5 MPa	≈ 18 MPa

Figure 1: Minimum and maximum principle stress tooth images for the first and second model.

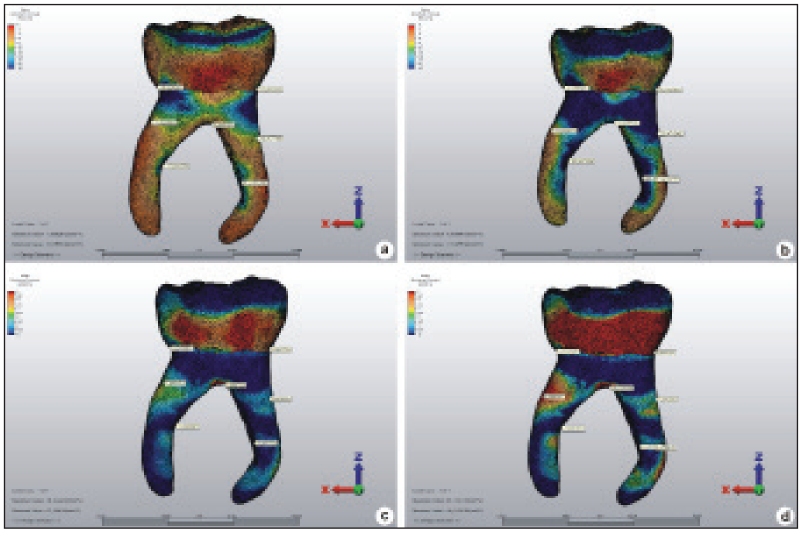
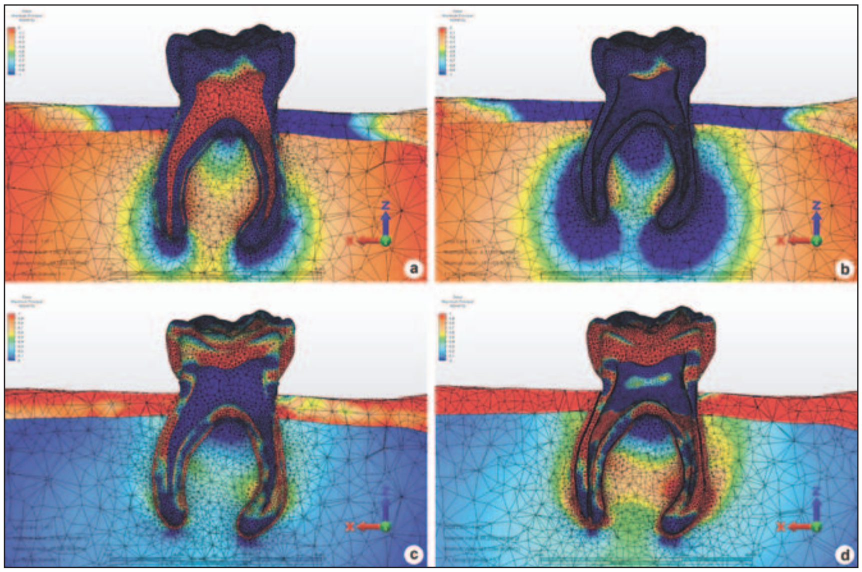


Figure 2: Minimum and maximum principle stress supporting tissue images for the first and second model.



DISCUSSION

Numerous studies have shown that the muscular and neuromuscular system development that occurs with age results in an increase in forces of mastication.[11,17,18,28,29] According to Owais *et al.,*[17] the most significant increase is seen in the transition between early and late mixed-dentition. It is possible that the root resorption and the subsequent ankylosis and infraocclusion of primary second molars observed in patients with congenital premolar agenesis are related to increases in masticatory forces;[11,13] thus, this study aimed to evaluate masticatory forces as a risk factor in dental and periodontal tissue pathologies of retained mandibular second molar teeth using FEA.

FEA analysis uses different types of stresses (including principal and von Mises stresses) to evaluate stress distribution.[30] While minimum and maximum principle stress values provide information about compressive and tensile stresses respectively,[14,31,32] von Mises stresses are calculated based on a combination of all principle stresses in order to provide more general information about stress distribution.[30] Given the differences in the ability of different biological tissue types to withstand compressive and tensile stresses, this study evaluated minimum and maximum principle stresses instead of von Mises stresses in order to provide more useful and detailed information, and the data that were obtained in the study were interpreted using visual, quantitative and qualitative comparisons instead of statistical analysis, which is not applicable to FEM analysis.[33]

Numerous studies have reported masticatory forces to increase with age.[17,18,28,29] Owais *et al* [17] reported masticatory forces of 289.28 N in mixed dentition, whereas Sathyanarayana and Premkumar[18] reported forces of 601.83 N for permanent dentition. Most studies[17,18,28,29] that evaluated masticatory forces during the transition from childhood to adolescence have assessed them in terms of "maximum bite force." Given that masticatory forces are known to increase with age, this study examined the stress produced during permanent dentition as an indication of the worst stress that a retained primary molar tooth would encounter in the long-term. In order to assess the distribution of masticatory forces to dental and periodontal tissue more accurately, the models simulated the application of forces to a solid object placed on the occlusal surface.

For both models, the minimum principle stresses were found to be concentrated mainly on the middle third of the internal root surfaces, to a lesser extent on the coronal third of the external root surfaces, and to a much lesser extent on the furcation region, indicating the internal root surfaces to be the area that is the most severely affected by compressive stress. In contrast, the maximum principle stresses were found to be higher on the external root surfaces, especially in the furcation region. Moreover, both the minimum and maximum principle stresses were found to be higher in the second model due to the greater masticatory forces that occur with increasing age.

The ability to tolerate stress varies among different types of biological dental tissue.[34] Dentinal tissue has a compressive strength of approximately 266 MPa[35] and a tensile strength of 52 MPa,[36] which is a clear indication of the ability of dental hard-tissue to better tolerate compressive stresses than tensile stresses. Thus, it may be understood that maximum principle stresses represent a greater risk-factor than minimum principle stresses, as regions subjected to maximum principle stresses are more likely to develop pathologies such as root resorption, ankylosis and infraocclusion. To avoid such issues, it is very important to reduce occlusal forces although it should be noted that none of the minimum and maximum stress values in this study exceeded the level of tolerance of the dental hard tissue.

This study found stresses on bone tissue to be lower than those on dental tissue. In both models, the minimum principle stress values on cancellous bone were concentrated around the furcation region, the root apex and around the cervical region of the tooth on the cortical bone. Moreover, in both models, the maximum principle stresses on the cancellous bone were found to be concentrated around the middle third of the tooth, whereas the distribution of maximum principle stresses on the cortical bone were more uniform. In both the types of bone, the stress values were found to increase with increases in masticatory forces.

The smaller stresses observed on the bone tissue in comparison to the dental hard-tissue may be explained by the fact that forces and stresses were absorbed by the periodontal ligament.[37,38] In an earlier FEA study which evaluated the function of the periodontal ligament,[38] the stress values on the bone without a periodontal ligament were found to be higher than the stress values on the bone attached to a periodontal ligament. Given this finding, it may be assumed that the presence of a healthy periodontal ligament will reduce the amount of stress to the bone tissue surrounding a persistent mandibular second molar subjected to increases in masticatory forces due to age, whereas the bone tissue of ankylosed persistent primary molars without a healthy periodontal ligament faced a greater risk.

CONCLUSION

When mandibular second primary molar teeth are retained in long-term, compressive stresses are more likely to act on their internal root surfaces, while more destructive tensile stresses may be expected to be focused on external root surfaces, especially around the furcation area. Both types of stresses are likely to increase with age. Dental tissue appears to be subjected to greater stress than bone tissues.

While all retained mandibular second primary molars do not suffer from root resorption and ankylosis resulting in infraocclusion, in cases where these pathologies are present, they may be associated with the increase in masticatory forces that occur with age. Further studies may be essential for comparing masticatory forces between the patients with and without these pathologies that were mentioned and for evaluating the effects of clinical approaches that may decrease the destructive increased masticatory forces on stress levels.

ACKNOWLEDGEMENT

This study was supported by Ankara University Scientific Research Projects Coordination Unit. Project Number: 14H0234004, 2016. The authors would like to thank Dr.Cees Kleverlaan for his contribution to this study.

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