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Original Research Article

The effects of erupting mandibular 3^{rd} molar on the dental arch: A FEM study

Avinash Kumar[1,*], Meghna Bhandhari[1], MD Baba Fareeduddin[2]

[1]*Dept. of Orthodontics & Dentofacial Research, Rajiv Gandhi University of health sciences, Kalaburgi, Karnataka, India*
[2]*Dept. of Orthodontics, ESIC Dental College and Hospital, Gulbarga, Karnataka, India*

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ABSTRACT

Introduction: Role of Erupting Mandibular 3^{rd} molars as a cause of incisor crowding in the lower arch continues to be controversial. The relation between 3^{rd} molar and dental crowding has not been established.
Aims and Objectives: To determine the area of stress distribution and tooth displacement during eruption of mandibular 3^{rd} molar in mesioangular and horizontal impaction.
Materials and Methods: Three dimensional finite element models were generated based on computed tomography scan data. From computed tomographic scans of a human mandible two additional finite element models were generated: a mandibular model with mesioangular impaction and second model with horizontal impaction. To investigate the stress distribution to the mandible, and tooth displacement eruptive force of 10 grams was applied.
Results: High concentration of stresses was seen at the inferior border of the mandible and lowest concentration of stress was present at symphysis for both the models. The tooth displacement for both mesio-angular and horizontal impaction caused mesial tilting of all the teeth i.e. from 2^{nd} molar to central incisor; with greatest tilting of 2^{nd} molar. Along the vertical plane, there was extrusion seen with 2^{nd} molar with mesio-angular impaction and extrusion in 2^{nd} molar and 1^{st} molar with horizontal impaction And all the teeth exhibited buccal flaring in case of both impaction.
Conclusion: There is significant level of tooth displacement from 2^{nd} molar towards the incisors. These changes occurring along the dental arch must be taken into consideration while planning for prophylactic extraction of third molars.

1. Introduction

Lower arch crowding is an ongoing source of controversy and concern in orthodontics. The role of 3^{rd} molars as a cause of incisor crowding, especially in the lower arch continues to be controversial. From the early beginning of orthodontics as a specialty, the presence of 3^{rd}molars was believed by orthodontists to be responsible for late crowding of the lower anterior teeth. Because this was frequently observed coincident with the timing of 3^{rd}molar eruption, clinicians were tempted to conclude a "cause and effect" relationship between these two phenomena. At a simplistic level, it was reasoned that vector forces from erupting 3^{rd} molars were pushed against second molars, causing mesial migration of the posterior teeth. The result was loss of available space and crowding. The relation between 3^{rd} molar and dental crowding has not yet been established. Clinicians have always been divided between supporters and opponents of anterior dental crowding caused due to the force generated by the 3^{rd} molar eruption. For the same reason, the surgical prophylactic approach for 3^{rd} molar has

* *Corresponding author*.
E-mail address: dr.avinashsajjan@gmail.com (A. Kumar).

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always been seen as the cure by the former and a 'placebo' by the latter.[1]

Late crowding of the lower incisor teeth is frequently observed after the eruption of the 3^{rd} molars, inciting the clinicians to deliberate a cause-and-effect relationship between the two events. The hypothesis is presumed that the mesial component of the forces created by the erupting 3^{rd} molars, transmitted through the dental arch, can create a mesial migration of the teeth culminating in the area of the incisors. The result is the inaugural loss of available space and crowding. Lower arch crowding that develops or increases after establishment of the permanent dentition during the teenage period, can be best described as post-adolescent crowding. The role of erupting 3^{rd} molars as a compel of such dental crowding has been the subject of controversy over the years.

Various theories have been proposed that account for late lower arch crowding which includes late mandibular growth, anterior component of force, lack of attrition in the modern population which may possibly cause mesial tilting of these teeth. This mesial axial inclination of permanent teeth gives rise to anterior component of force. Anterior component of force is an occlusal force dissipated axially and in the mesial direction, i.e. towards the frontal region of the mouth. This force is transmitted through the proximal tooth contacts of teeth, anterior to the mesially tilted 3^{rd} molars. This force produced by 3^{rd} molar has a possible role in mesial migration of teeth anterior to it. Subsequently, this might be the reason of malalignment of anterior teeth and crowding. In the year 1961, Bergstorm[2] was among one of the first authors to analyze the influence of 3^{rd} molars in the developing dental arch crowding and reported that there was a relationship between wisdom teeth and incisor crowding. Bishara et al[3] evaluated changes in the dental arches between 25 and 45 years of age and concluded that both sexes experienced a significant increase in dental crowding in both the dental arches, however the severity was more pronounced in the lower arch especially in the lower anterior segment. Later, Vego's[4] study concluded that the eruption of lower 3^{rd} molars exerted a force on neighbouring teeth as well. On the contrary to this, Broadbent[5] supported the opposite theory, that the presence of 3^{rd} molars had no influence on crowding. Sidlauskas[6] also reported that there is no co-relation between 3^{rd} molar and anterior crowding.

The finite element analysis (FEA) is an upcoming and significant research tool for biomechanical analyses in biological research. It is an ultimate method for modeling complex structures and analyzing their mechanical properties. FEA has now become widely accepted as a non-invasive and excellent tool for studying the biomechanics and the influence of mechanical forces on the biological systems. It enables the visualization of superimposed structures, and the stipulation of the material properties of anatomic craniofacial structures. It also allows in establishing the location, magnitude, and direction of an applied force, as it may also assign stress points that can be theoretically measured. Further, as it does not affect the physical properties of the analyzed materials it is easily repeatable. Thus, finite element-three dimensional analysis gives more accurate, adaptable and clear picture of the areas of tooth displacement and stress effects of erupting 3^{rd} molars on lower anterior crowding. Thus, the study aims in determining the areas of stress distribution and tooth displacement caused by erupting 3^{rd} molar.

2. Materials and Methods

FEA has been developed into a branch of applied mathematics for numeric modelling of physical systems, which is used in many engineering disciplines. In its simplest mathematical terms, this numerical technique is used to find approximate solutions for partial differential and integral equations through the generation of meshes of a continuous domain for a set of discrete sub domains or elements. Numerical methods are then used to predict the behaviour of the object in question in various situations, for example, under conditions of loading.[7]

The external forces and the mechanical properties/geometry are used to calculate the nodal displacements; the differentiation of the displacement field yields the strain distribution; and the stress distribution is determined mathematically.

The mandibular model was developed from a patient without any gross defects or discontinuity in the anatomy. The model had a set of permanent dentition with normally erupted teeth, without any crowding or spacing and impacted 3^{rd} molar on one side and a normally erupted 3^{rd} molar on the other side. Computed tomographic (CT) scan images of the mandible were made in the axial direction at 0.5mm intervals in the horizontal plane. The study aimed to determine the stresses and displacements exerted by the mandibular 3^{rd} molar.

In this study, CT scan of the mandible will be used to build a 3 – dimensional FEA model. There were 2 finite element models constructed, the first one with mesio-angular impaction and the other with a horizontal impaction. As mentioned in the literature, the eruptive force of tooth was found to be between 5-10 grams,[8–12] the models using 10 grams of force will be taken into account for determining the areas of maximum stress and tooth displacement. The software used for geometric modeling was Solid Works. Individual CT scan sections will be imported into the Solidworks and traced, taking care so as not to distort the anatomy of the region. Each traced sections will be then placed one above the other to give a mandibular model in Solidworks. These blocks will be imported into Altair HyperMesh. The software which will be made use in present study is Hyperworks 13.0, Altair, Troy, Michigan, United States.

2.1. Generation of CAD Model

The geometric model obtained is converted to finite element model using Altair HyperMesh software. FEM has been applied successfully to study stress and strain in the field of engineering and in living structure. The FEM is composed of an aggregate of small elements that are sufficient to describe the geometry of the subjects. This is called 'creating the mesh or meshing'. The mesh intersections are called nodes. The contour data of the profiles created by surface scanning were transformed into the x, y and z co-ordinate points and read by Finite element program HyperWorks. Connecting these coordinate points gave line geometry also called as wire frame modeling. Connecting the lines of each section gave surface geometry.

2.2. Generation of finite element model

The finite element modelling is the representative of geometry in terms of finite number of elements and nodes. This process is called discretization. The main idea behind discretization is to improve the accuracy of the results. Subdivide i.e. discretize the complex geometry into suitable set of smaller "elements" of finite dimensions (2D or 3D). The points connecting two or more discrete elements are called as nodes or nodal points. The corner nodes are called primary external nodes. The additional nodes which occur on the sides of the elements are called secondary external nodes. The secondary nodes have fewer displacements than corner nodes. For this study Tetrahedron elements were used. Images of the Mesh are as shown (Figure 1).

Number, size and type of element are decided. Practical knowledge and judgement are needed to limit the number of elements to minimum amount conductive to acceptable results (Table 1). The material properties of the bone and teeth in the model were defined according to experimental data from previous studies (Table 2).

The boundary conditions are defined to simulate how the model is constrained and to prevent it from free body motion. Restrains will be established at all nodes lying at the lower border of the mandibular bone lying on the symmetric plane and appropriate boundary conditions are imposed.

2.3. Loading configuration

For determining the changes, 10 grams of force in both the horizontal and mesio-angular impaction of mandibular 3^{rd} molar will be used.

3. Results

3.1. Stress distribution

When the eruptive forces were applied on the mandible, the stresses were observed at symphysis, body of the mandible, inferior border of the mandible, anterior border of ramus and the retro molar area in both models. Even though the stresses were generally distributed throughout the mandible, a high concentration of stresses was present at the inferior border of the mandible and lowest concentration of stress was present at symphysis for both the models. The stresses were also concentrated in the body of the mandible, inferior border of the mandible, anterior border of ramus and the retro molar area (Table 3).

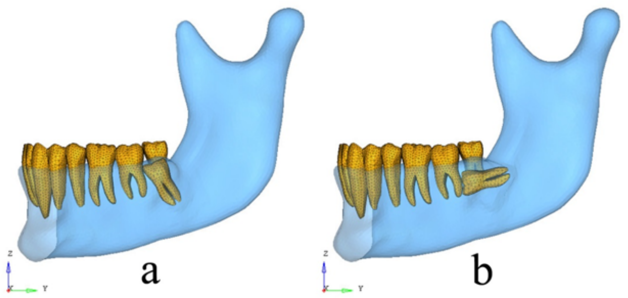

Fig. 1: a: FEM model 1- Mesioangular impaction; **b:** FEM model 2- Horizontal impaction.

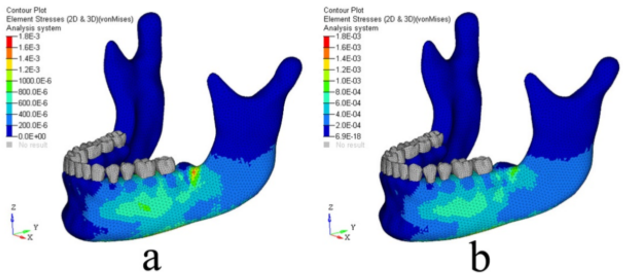

Fig. 2: Stress distribution in the mandible – Buccal view; **a:** Mesio-angular impaction; **b:** Horizontal impaction.

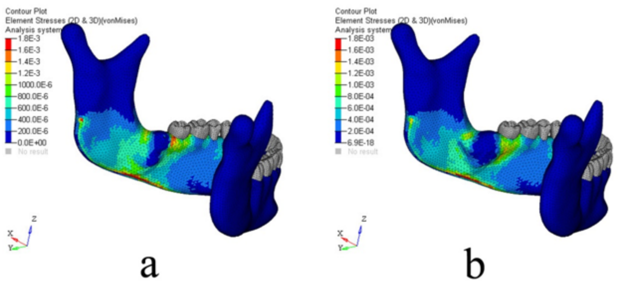

Fig. 3: Stress distribution in the mandible – Lingual view. a) Mesio-angular impaction. b) Horizontal impaction.

Table 1: Meshing details

Model	Mesioangular.		Horizontal.	
Component.	No. of nodes.	No. of elements.	No. of nodes.	No. of elements.
Teeth.	23287	107429	23287	107429
Periodontal Ligament.	69774	104827	69824	106443
Alveolar bone.	55622	286750	56551	292497

Table 2: Material property data representation.

Material	Young's Modulus (Newton/Mm2)	Poisson's Ratio
Teeth	20.3 × 103	0.30
Compact bone	13.7× 103	0.30
Cancellous bone	79 ×102	0.30
Periodontal ligament	68.9	0.45

Table 3: Tabular presentation of stress distribution in mandible.

Areas of Mandible.	Mesioangular Impaction.	Horizontal Impaction.
Symphysis.	2.0E-004.	2.0E-004.
Body of mandible.	8.2E-004.	7.5E-004.
Angle of mandible.	9.3E-004.	8.2E-004.
Retromolar area	1.5E-003.	1.4E-003.
Anterior border of ramus.	1.4E-003.	7.1E-004.
Inferior border of mandible.	2.1E-003.	2.1E-003.

Table 4: Displacement of teeth in all three axis.

Teeth	Mesioangular Impaction			Horizontal Impaction.		
	X-axis.	Y-axis.	Z-axis.	X-axis.	Y-axis.	Z-axis.
Central Incisor	1.80E-07	-1.60E-07	-5.70E-08	1.80E-07	-1.40E-07	-4.80E-08
Lateral Incisor	2.00E-07	-2.60E-07	-8.90E-08	2.20E-07	-2.50E-07	-7.30E-08
Canine	2.80E-07	-4.00E-07	-4.00E-08	4.20E-07	-5.20E-07	-1.82E-07
1st Pre-Molar	5.30E-07	-7.00E-07	-2.10E-07	5.10E-07	-6.90E-07	-2.20E-07
2nd Pre Molar	9.50E-07	-9.00E-07	-1.20E-07	9.50E-07	-8.90E-07	-1.10E-07
1st Molar	1.60E-06	-1.30E-06	-2.70E-07	1.60E-06	-1.20E-06	6.80E-09
2nd Molar	2.10E-06	-1.60E-06	1.30E-07	2.00E-06	-1.60E-06	9.90E-08

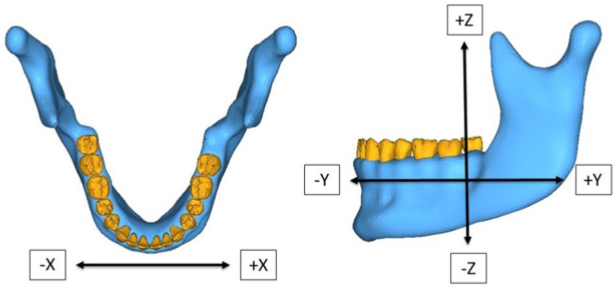

Fig. 4: Tooth displacement in three planes of axis.

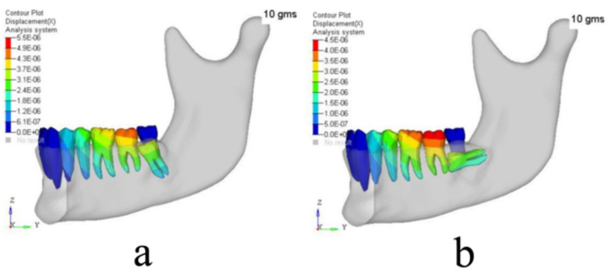

Fig. 5: Tooth displacement in Y and Z axis.

3.2. Tooth displacement

The present study also determines the amount of tooth displacement caused by mesio-angular and horizontally impacted 3^{rd} molar on the adjacent teeth. The displacements in both the impactions were registered in sagittal plane (Y-axis), vertical plane (Z-axis), buccolingual (X-axis) directions (Figure 4; Table 4).The displacement brought about by 10 grams of force for both mesio-angular and horizontal impaction caused mesial tilting of all the teeth i.e. from 2^{nd} molar to central incisor; with the greatest tilting of 2^{nd} molar. (Figure 5)

A line passing from the long axis of impacted third molar (mesio-angular and horizontal) and second molar is

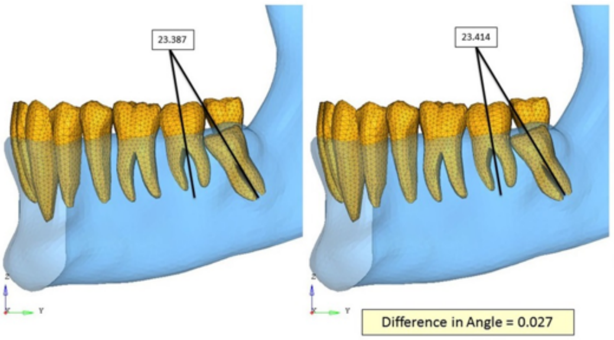

Fig. 6: Mesioangular impaction- Angular changes before and after force application.

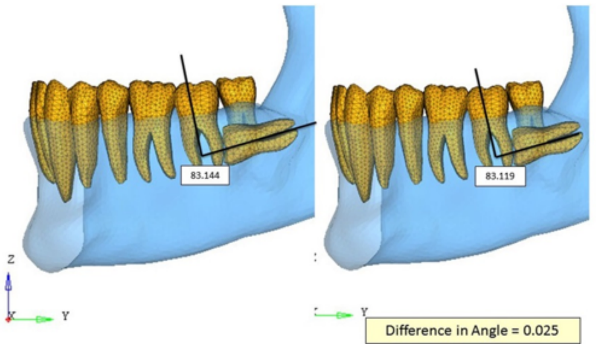

Fig. 7: Horizontal impaction- Angular changes before and after force application.

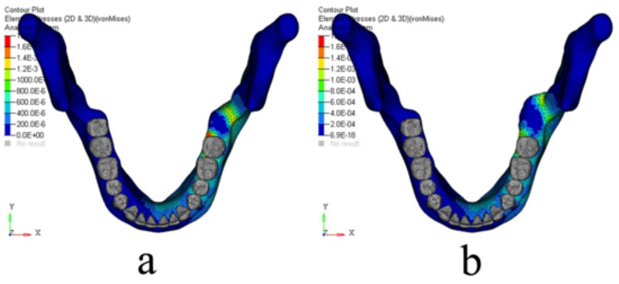

Fig. 8: Tooth displacement in X-axis.

constructed. The angle at the point of intersection of both the long axis was measured before and after the application of force. For mesio-angular impaction an increase of 0.027 degrees of angle, whereas in horizontal impaction a decrease of 0.025 degrees of angle is seen (Figures 6 and 7).

When seen along the vertical plane, there was extrusion seen with 2^{nd} molar with mesio-angular impaction and extrusion in 2^{nd} molar and 1^{st} molar with horizontal impaction (Figure 5). And all the teeth exhibited buccal flaring in case of both impactions (Figure 8; Table 4).

4. Discussion

It is important to understand the stress distribution of erupting 3^{rd} molar, as it helps in determining, the cause of dental crowding that has been a subject of controversy over the years. The use of FEA in this study has described, about the stress distribution in three-dimensional pattern. The study of tooth movements in all three planes is being introduced for the first time. Even the smallest changes are being detected using the finite element model, which was not possible in all the previous clinical studies.[8–12]

In this study, it is observed that stress is distributed along the symphysis, body, and angle, inferior border of the mandible, anterior border of ramus and the retro molar area in both the model. Highest concentration of stress is present at the inferior border of the mandible (2.1E-3MPa) and lowest concentration of stress is at symphysis (2.0E-4MPa). However, when comparing the two models, higher areas of stresses are seen with mesio-angular impaction (Table 4) which might be due to a smaller area of contact as compared to horizontal impaction. This is valuable information as mesio-angular impaction, are the most common impaction.

The tooth displacements in both impactions are registered in sagittal, vertical and, buccolingual direction. According to Sakuda et al.,[13] crowding can cause displacement at any interproximal contact, with the highest incidence of contact between cuspids and lateral incisors. Along the sagittal plane, greater tilting of 2^{nd} molar is seen and gradually reducing to incisors, all the teeth exhibited mesial tilting, which is consistent with the finding of Richardson[14] which states that late anterior crowding is associated with mesial movement of teeth rather than lower incisor retroclination. According to Sumitra et al.[15] anterior component of occlusal force (ACF) is important in the discussion of late lower arch crowding. This is because it's possible role in causing mesial migration of teeth and subsequent dental mal-alignment. The axial inclination of permanent teeth is such that the forces of mastication produce a mesial resultant through the contact points of teeth. ACF is thought to result from axial inclination of posterior teeth which causes these teeth to tip forward during occlusal loading. This tendency of teeth to move forward varies greatly according to the angulations of teeth and by the steepness of occlusal plane.

In case of mesio-angular impaction there is a mesial inclination of the 3^{rd} molar towards the long axis of 2^{nd} molar at an angle of 0.027 degrees (Figure 6) whereas, in case of horizontal impaction the angle is 0.025 degrees (Figure 7), which is supported by study conducted by Artun et al.,[16] which showed higher frequency of mesial angulation of 3^{rd} molar in patients with impactions. But these studies are contrary to the study of Pirttiniemi et. al.,[17] who concluded by his study that there is a slight distal drift of 2^{nd} molar with no significant change in the lower incisor region. The present study describes about the stress distribution in mesio-angular and horizontal impaction which was not mentioned in the previous studies.[8–12]

In vertical plane, there is extrusion with 2^{nd} molar whereas all the other teeth exhibited intrusion in case of mesio-angular impaction, whereas in case of horizontal impaction extrusion is seen with 2^{nd} molar and 1^{st} molar and intrusion with all the other teeth. Along the buccolingual direction, in both the impaction all the teeth exhibited buccal flaring in which highest flaring is seen with 2^{nd} molar (Table 4). This is similar to the result by Richardson who concluded that mesial inclination of lower canine is usually considered to be a sign of buccal segment moving forward. However, this finding is against the suggestion by Southard et al., who measured mesial force exerted by unerupted 3^{rd} molar using a technique similar to measuring the anterior component of occlusal force. The mesial force increases tightness of all the proximal tooth contacts with no flaring and that surgical removal of 3^{rd} molar will relieve the tightness by eliminating this force.

4.1. Limitations of the Study

FEM will give results with a greater degree of accuracy, but this approach has certain limitations, such as its inability to measure accurately the biological dynamics of the tooth and its supporting structure.[18] The eruptive forces of the teeth are continuous process, however, the forces used in this study are not continuous, as it is not possible for the software to simulate the natural eruptive process. A common error in finite element models of bone in the literature is assigning one Young's modulus value to cortical bone and another to trabecular bone. Bone is a heterogeneous, anisotropic composite biomaterial which has variable Young's modulus based on its mineral content, thus the stress distribution in the present study may differ from the results obtained in the biologic subjects.

5. Conclusion

The results of finite element method simulations tested in the present study indicated that:

1. The magnitude of stress is more with mesio-angular than horizontal impaction.
2. High concentration of stress is present at the inferior border of the mandible whereas lowest concentration of stress is present at symphysis for both the models.
3. Along the sagittal axis, there is mesial tilting of all the teeth in both the impaction, which gradually decreased from 2^{nd} molar to central incisor.
4. Along the vertical axis, in mesio-angular impaction there is extrusion of 2^{nd} molar and intrusion with all the other teeth whereas, in horizontal impaction there is extrusion of 1^{st} and 2^{nd} molar and also intrusion of all the other teeth.
5. Along the bucco-lingual axis, buccal flaring of the teeth is seen.

From our finite element study data, it can be concluded that there are significant level of tooth displacement from 2^{nd} molar towards the incisor after application of mandibular third molar eruptive force. These changes occurring along the dental arch must be taken into consideration while planning for prophylactic extraction of third molars.

6. Source of Funding

None.

7. Conflict of Interest

None.

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Author biography

Avinash Kumar, Professor

Meghna Bhandhari, Post Graduate

MD Baba Fareeduddin, Senior Lecturer

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