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Optimum force system for intrusion and extrusion of maxillary central incisor in labial and lingual orthodontics

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ABSTRACT

Background: The objective of the present study was to specify an optimum force system for intrusion and extrusion of maxillary central incisor and to compare the effects of bracket positioning at different heights from the incisal edge in Labial Orthodontics (LaO) and Lingual Orthodontics (LiO).
Methods: A mathematical model of maxillary central incisor with normal inclination was developed. Four cases of heights of bracket slot from incisal edge were considered both in LaO and LiO viz. 3 mm, 4 mm, 5 mm and 6 mm. Based on a mathematical model, an optimum force system consisting of an intrusive or extrusive force (F) and a moment (M) was devised and moment (M) to force (F) ratio (M:F ratio) was estimated in each case. Then, three-dimensional Computer Aided Design (CAD) models of incisor and surrounding structures were prepared. To validate an optimum force system, finite element analysis was carried out and force system with derived M:F ratio was applied in each case.
Results: In finite element analysis, results were shown in the form of vector graph of nodal displacements along with undeformed and deformed models. The desired intrusion or extrusion of incisor was observed. Thus, force system devised from a mathematical model was validated with finite element analysis in each case.
Conclusion: To achieve intrusion or extrusion, M:F ratios required in LaO were same i.e. 8:1 for aforementioned heights of bracket slot from incisal edge but different in LiO i.e. 0:1, 1:1, 2:1 and 3:1 for the heights of 3 mm, 4 mm, 5 mm and 6 mm respectively.

1. Introduction

Tooth displacement is an outcome of continuous orthodontic force system due to remodeling of the surrounding bone structure. For the best orthodontic treatment, an optimal external force system should be determined so that tooth movement can be estimated and controlled [1–4]. Accurate application of basic biomechanical principles in orthodontic treatment simplifies the force system. It improves the efficiency of the orthodontic appliance and obviates any side effects. Thus, more predictable tooth movement can be achieved [1].

Emphasis should be given to the significance of tooth morphology. Accurate position and orientation of the maxillary and mandibular incisors is a crucial factor for stability, function and esthetics purpose [5–9]. The most discernible teeth in the oral cavity are the maxillary central incisors that can be easily distinguished from the other teeth [10,11].

Biomechanical principles of Lingual Orthodontics (LiO) are different from Labial Orthodontics (LaO). If a particular force system produces bodily displacement of tooth in LaO, crown tipping will occur in LiO and vice-versa [12]. Further, LiO is more esthetic orthodontic technique than LaO [13]. In case of vertical forces, the Center of Resistance (C_{res}) of the tooth is closer in LiO. Besides providing good esthetics, this biomechanical advantage demands lesser force or moment values, which will be more within the biological limit.

Finite element analysis has been established as an effective tool for the simulation and analysis of tooth structures [11–20]. It is a quick, accurate and inexpensive method to apply biomechanical forces and analyze results. The main steps in finite element analysis are pre-processing, processing and post-processing [15]. Pre-processing involves three-dimensional geometric modeling of a structure, meshing i.e. discretization into smaller elements connected by nodes, assigning appropriate material properties, loads and boundary conditions. Processing involves solving a set of simultaneous equations with numerous variables to converge the solution. The last step post-processing

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involves graphical representation of analysis results to compare the stress–strain variations, undeformed and deformed structure at nodes and elements.

Application of simply intrusive or extrusive force causes uncontrolled crown tipping of tooth. This uncontrolled tipping should be prevented so that intrusion or extrusion of tooth will occur. Clinically, application of labial and lingual appliances has different effects on tooth movement. However, very few studies have compared intrusion and extrusion of incisors between LaO and LiO [1,2].

For this study, maxillary central incisor was considered as it is the most prominent tooth in the oral cavity. In this study, a mathematical model of maxillary central incisor was developed taking various factors into consideration i.e. normal inclination of incisor, position of center of resistance (C_{res}), distance of labial bracket slot from tooth surface, distance of lingual bracket slot from tooth surface and height of bracket slot from incisal edge. Four cases of height of bracket slot were considered, i.e. 3 mm, 4 mm, 5 mm and 6 mm. If any of the above factors is not considered, then it will affect the calculated value of distance (D) between point of force application (P_f) on bracket slot and C_{res}. Hence, it will alter the values of required force system. So, consideration of all these factors is necessary to devise an optimum force system. To the best of our knowledge, no study has been performed to establish an optimum force system for intrusion and extrusion of maxillary central incisor both in LaO and LiO considering the aforementioned factors. Thus, this study provides a unique optimum force system.

The aim of the present study was to specify an optimum force system for intrusion and extrusion of maxillary central incisor and to compare the effects of bracket positioning at different heights from the incisal edge in LaO and LiO. The force system devised from a mathematical model was compared and validated with finite element analysis in each case.

2. Materials and methods

There are two permanent maxillary central incisors viz. right and left. The maxillary central incisors are the neighboring teeth in the maxilla with their mesial surfaces in contact with each other. Anatomically, these teeth are identical. Hence, they perform similar functions. In this study, right maxillary central incisor was selected.

2.1. Mathematical model

The equivalent force system at C_{res} due to single intrusive or extrusive force (F) i.e. at a distance (D) from C_{res} is a force and a moment developed due to force. Hence, single intrusive or extrusive force (F) produces intrusion or extrusion respectively along with uncontrolled crown tipping. To prevent this tipping, counter-acting moment (M) along with force (F) was applied on the bracket slot so that equivalent force system at the C_{res} was only single intrusive or extrusive force. Thus, the force system at the bracket slot was a single intrusive or extrusive force (F) and a moment (M) i.e. clockwise or counter-clockwise. This force system was applied in a proper Moment to Force (M:F) ratio according to the position of brackets in LaO and LiO to obtain intrusion or extrusion of tooth. To calculate M:F ratio, a mathematical model of maxillary central incisor was developed. The point on bracket slot where force was applied is also called as point of force application (P_f).

The basic anatomic and geometric features of the right permanent maxillary central incisor were taken from Wheeler's dental anatomy; physiology and occlusion [21]. The cervico-incisal length of crown and root were 10.5 mm and 13 mm respectively.

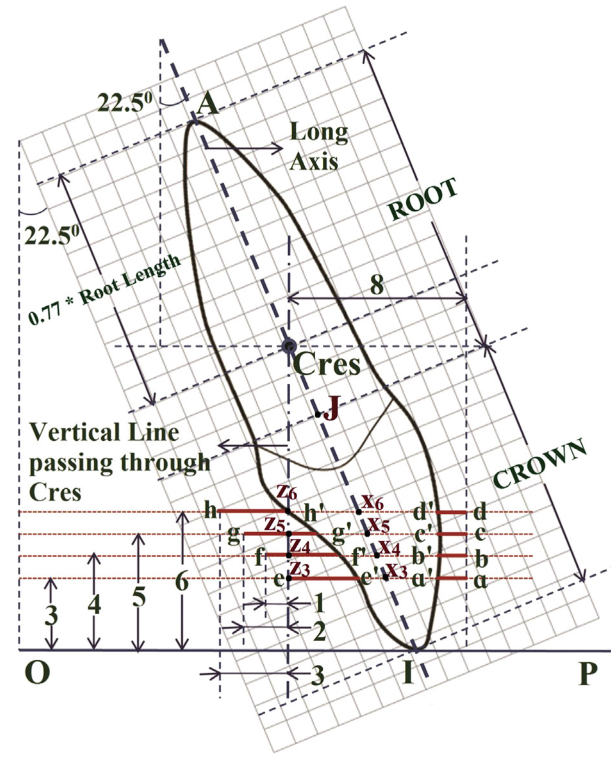

Fig. 1. Mathematical model of right maxillary central incisor with distances of labial and lingual bracket slots as viewed from the distal side [all length dimensions are in mm].

The normal inclination of long axis of maxillary central incisor was taken as 22.5° with respect to vertical plane [3]. The position of C_{res} was taken approximately 0.77 of the root length from the apex on the long axis [22]. The force system was applied on the bracket slot. So, the horizontal distance between the bracket slot and tooth surface was considered to be 1.2 mm for labial and 3 mm for lingual side respectively [1]. The height of bracket slot from the incisal edge (I) i.e. perpendicular to Occlusal Plane (OP) was varied from 3 to 6 mm at an interval of 1 mm. In this way, a mathematical model of maxillary central incisor was developed (Fig. 1).

Several points were defined on the model i.e. points along the long axis of tooth and points along a line parallel to the OP that passes through the labial and lingual bracket slots. The points defined on the long axis of the tooth were, I=incisal edge, C_{res}=center of resistance, J=point joining crown and root on long axis of tooth, A=root apex. The points on the lines parallel to OP are shown in Table 1.

In mathematical model,

Length of Crown, $L_{crown} = IJ = 10.5$ mm

Length of Root, $L_{root} = AJ = 13$ mm

The horizontal distance between bracket slot and tooth surface was considered as 1.2 mm and 3 mm in LaO and LiO respectively.

In LaO, $aa' = bb' = cc' = dd' = 1.2$ mm

In LiO, $ee' = ff' = gg' = hh' = 3$ mm

The horizontal distances within tooth i.e. between tooth surface and long axis of tooth at different heights of bracket slot were determined graphically with enlarged scale as, $a'x_3 = 2.9$ mm, $b'x_4 = 3.3$ mm, $c'x_5 = 3.7$ mm, $d'x_6 = 4.1$ mm,
$e'x_3 = 0.9$ mm, $f'x_4 = 1.5$ mm, $g'x_5 = 2.1$ mm, $h'x_6 = 2.7$ mm

The basic trigonometric equations were applied to calculate M:F ratio.

$$I_{x_3} = \frac{3}{\cos(22.5^\circ)},\ I_{x_4} = \frac{4}{\cos(22.5^\circ)},\ I_{x_5} = \frac{5}{\cos(22.5^\circ)},\ I_{x_6} = \frac{6}{\cos(22.5^\circ)} \quad (1)$$