

# Stress Distribution Evaluation of the Periodontal Ligament in the Maxillary Canine for Retraction by Different Alveolar Corticotomy Techniques: A Three-dimensional Finite Element Analysis

<sup>1</sup>Ariel Adriano Reyes Pacheco, <sup>2</sup>Armando Yukio Saga, <sup>3</sup>Key Fonseca de Lima, <sup>4</sup>Victor Nissen Paese, <sup>5</sup>Orlando M Tanaka

## ABSTRACT

**Aim:** By using the finite element method (FEM), this study aimed to evaluate the effect of different corticotomy formats on the distribution and magnitude of stress on the periodontal ligament (PDL) during retraction of the maxillary canine.

**Materials and methods:** A geometric model of the left hemi-jaw was created from computed tomography scan images of a dry human skull and loads were administered during distalization movement of the canine. Three trials were performed: (1) without corticotomy, (2) box-shaped corticotomy and perforations in the cortical bone of the canine (CVC) and (3) CVC and circular-shaped corticotomy in the cortical bone of the edentulous space of the first premolar.

**Results:** There was no difference in stress distribution among the different corticotomy formats.

**Conclusion:** Different corticotomy formats used to accelerate orthodontic tooth movement did not affect stress distribution in the PDL during canine retraction.

**Clinical significance.** From a mechanical perspective, the present study showed that the stress distribution on the PDL during canine retraction was similar in all the corticotomy formats. When using the Andrews T2 bracket, the PDL presented the highest levels of stress in the middle third of the PDL, suggesting that the force was near the center of resistance. Also, as bone weakening by corticotomies did not influence stress distribution, the surgical procedure could be simplified to a less aggressive one, focusing more on inflammatory cellular stimulation than on bone resistance. A simpler surgical act could also be performed by most orthodontists in their practices, enhancing postoperative response and reducing patient costs.

**Keywords:** Corticotomy, Finite element analysis, Periodontal ligament, Tooth movement.

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## INTRODUCTION

There is an increase in the number of adult patients who attend orthodontic offices seeking short fast treatment to improve the esthetics and function of their teeth.<sup>1</sup> Orthodontic tooth movement (OTM) is a force-related aseptic and acute inflammatory process, but the forces applied to the tooth are not uniform and the tissue remodeling response is variable.<sup>2</sup> The OTM rate is associated with age, stress distribution and magnitude of the lesion on the periodontal ligament (PDL).<sup>3-5</sup> Heavy forces can result in PDL hyalinization, reduce OTM and increase the overall treatment time.<sup>6</sup>

<sup>1</sup>Department of Orthodontics, Pontifícia Universidade Católica do Paraná, School of Health and Biosciences Curitiba, Brazil

<sup>2</sup>Residency in Orthodontics. Pontifícia Universidade Católica do Paraná, School of Health and Biosciences Curitiba, Brazil

<sup>3</sup>Graduate Program in Mechanical Engineering. Pontifícia Universidade Católica do Paraná School of Health and Biosciences, Curitiba, Brazil

<sup>4</sup>Mechanical Engineering Undergraduate Student. Pontifícia Universidade Católica do Paraná, School of Health and Biosciences, Curitiba, Brazil

<sup>5</sup>Graduate Program in Orthodontics, Pontifícia Universidade Católica do Paraná, School of Health and Biosciences Curitiba, Brazil. Postdoctoral Fellow at The Center for Advanced Dental Education at Saint Louis University, MO

**Corresponding Author:** Orlando M Tanaka, Full Professor Department of Orthodontics, Pontifícia Universidade Católica do Paraná, Paraná, Brazil, CEP: 80215-901, Phone: 554132711637, e-mail: tanakaom@gmail.com

Corticotomy is a surgical procedure such as cuts or perforations limited to the cortical bone, which visualizes to reduce treatment time by increasing cellular activity and reducing bone resistance.<sup>7</sup> The technique was initially performed by creating independent bone blocks<sup>8</sup>; however, it fell in disuse because of the high degree of invasiveness and postsurgical complications.<sup>9</sup> It was later reintroduced with modifications that included the nonperformance of bone fractures and included guided bone regeneration procedures to minimize possible adverse effects such as dehiscence or fenestration caused by the expansive tendency of the procedure.<sup>1,10,11</sup> It has been proven that a corticotomy can accelerate OTM by three to four times.<sup>12,13</sup> However, the mechanism of how a corticotomy accelerates OTM is not fully understood and has not been proved in humans.

The finite element method (FEM) has been used in biomechanical studies of orthodontic movement. It is a mathematical method that evaluates the resulting stress when applying a load or displacement on bodies,<sup>14</sup> such as teeth, PDL and cortical and trabecular bone.

Stress in the PDL can be used as a factor to stimulate changes in the behavior of cells responsible for bone remodeling in orthodontic tooth movement.<sup>15</sup> To date, studies have evaluated the effect of a corticotomy by using cone-beam tomography,<sup>16</sup> microtomography,<sup>17,18</sup> radiography and histological sections of animals;<sup>19</sup> however, studies are lacking that evaluate the stress distribution in the PDL by using different osteotomy formats on the cortical bone and applying FEM.

Based on the principles that stress distribution is more important than the magnitude of the applied force, and that the corticotomy procedure accelerates OTM, the aim of the present study was to use FEM to evaluate whether corticotomy produces differences on the stress distribution in the PDL during retraction of the maxillary canine.

## MATERIALS AND METHODS

The present model was made from cone-beam tomography images obtained from a dry human skull with permanent teeth at the Department of Anatomy at Catholic University of Paraná (PUCPR). For our study, an I-CAT scanner (CAT-I Classic; Imaging Sciences, Hatfield, PA) was operated at 120 kVp, 0.5 mm nominal focal spot size, 14-bit dynamic range gray scale and 0.25-mm voxel size, which produced 256-bit image slices of 0.25 mm thickness that were converted into exportable files in DICOM format.

To define the anatomical limits of each component of the model (i.e., cortical bone, cancellous bone, enamel, dentin and PDL) we used Simpleware CAD program (Innovation Centre, Exeter, UK). The 0.25-mm spacing between the root and the tooth socket surface was considered the thickness of the PDL. To simplify the

process, only one hemi-maxilla was used. To create the geometric model, the images obtained by the tomography scan were transferred to SolidWorks software, version 2013 (Dassault Systèmes SolidWorks Corp., Concord, MA, USA) for surface correction. In this phase, the overlapped surfaces were removed, the intersections and abrupt surface changes were softened and the empty spaces created by removing the nerves and vascularization were corrected. The tube, the arch and the brackets were added to the solid model. The different corticotomy formats and the first premolars were removed in this phase. The corticotomies were performed with depths that did not exceed the thickness of the cortical bone.

The diameter of the perforations and the width of the osteotomies were equal to 1.5 mm. Brackets and an orthodontic arch segment were also modeled in this program. Prescription type T2 Andrews brackets with a power arm for left maxillary canine traction were the references for modeling the brackets and tube (Ortho Organizers, Carlsbad, CA) with a slot of 0.022 × 0.025 inch. The arch segment was modeled with a stainless steel arch of 0.019 × 0.025 inch. The measures for the modeling were obtained using a microscope (Nikon Profile Projector V-16E; Nikon Corp., Tokyo, Japan) and a digital readout (Quadra-Chek 2000 Readout Series; Metronics, Traunreut, Germany).

The solid was exported to the finite element program Autodesk Multiphysics Simulation 2013 (Autodesk, San Rafael, CA). A finite element mesh was created for each model component (i.e., cortical bone, cancellous bone, PDL, enamel, dentin and steel) and their mechanical properties were implemented in the finite element program (Table 1).<sup>20-23</sup>

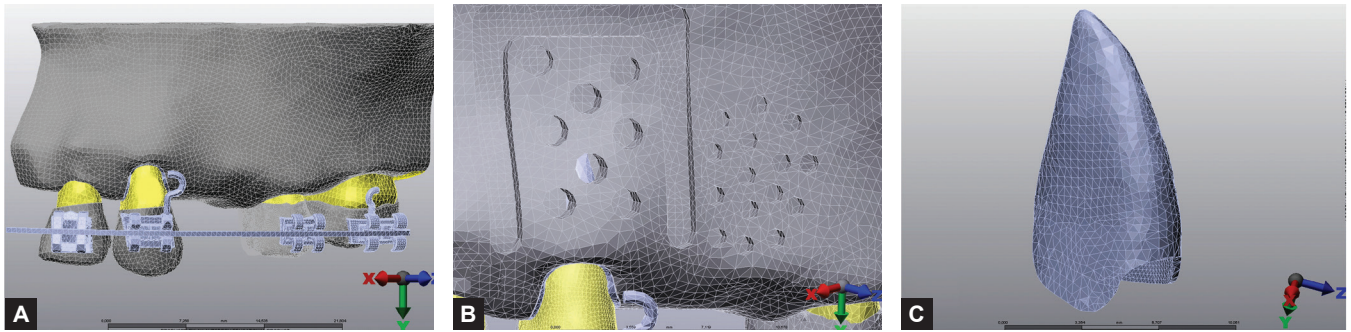
For the boundary conditions, the translational movement in the *x*, *y* and *z* directions was restricted in the lateral faces and the upper extremity of the hemi-maxilla and the only tooth able to move was the canine. The force applied to the power arm to simulate canine retraction was 150 gf.<sup>24</sup>

After the convergence analysis of the stress value, the mesh size was defined so that the finite element analyses could be performed. The variations in the length of the edges of the elements ranged between 0.375 and 0.500 mm.

**Table 1:** The Young Module and Poisson's Coefficient

Material	Young module (MPa)	Poisson's coefficient
Periodontal ligament	0.87	0.35
Enamel	84100	0.2
Dentin	18600	0.31
Cortical bone	13800	0.26
Trabecular bone	345	0.38
Stainless steel	200000	0.3

Malek et al, 2011.<sup>21</sup> Quian et al, 2008.<sup>22</sup> Kojima and Fukui, 2006.<sup>20</sup> Xia et al, 2013.<sup>23</sup>



**Figs 1A to C:** (A) The mesh created by using Autodesk Simulation Multiphysics 2013 software (Autodesk, San Rafael, CA, USA). (B) The canine's meshed periodontal ligament model

The final mesh was formed by 1,256,452 linear tetrahedral elements and 113,840 nodes (Figs 1A to C). The model was homogeneous and isotropic, homogeneous and isotropic, and it has linear elastic behavior. The stress fields over the finite element model were measured by the von Mises criteria for ductile materials. These considerations are used in orthodontics.<sup>25,26</sup>

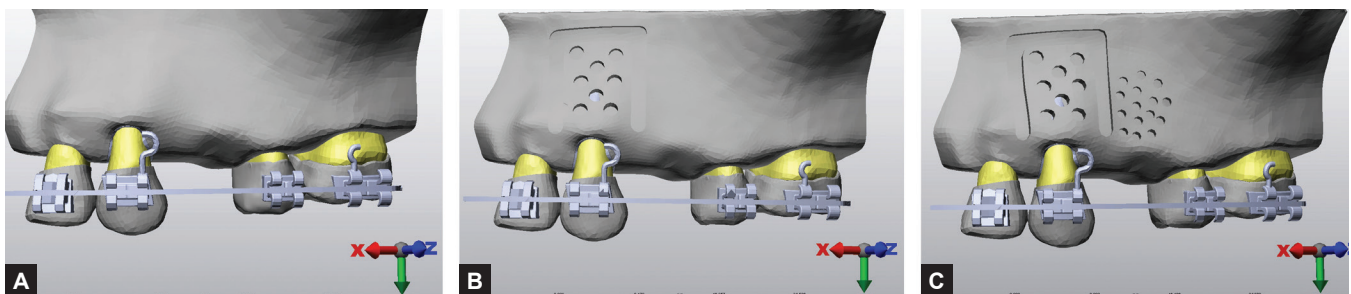
Three canine distalization possibilities were assessed (Figs 2A to C): (1) No corticotomy and no drilling in the cortical bone (i.e., the control), (2) box-shaped corticotomy and perforations in the cortical bone of the canine, and (3) condition B along with circle-shaped corticotomy in the cortical bone of the first premolar. After completing the tests, the distribution of stress was evaluated in the mesial and distal sides of the PDL of the canines.

## RESULTS

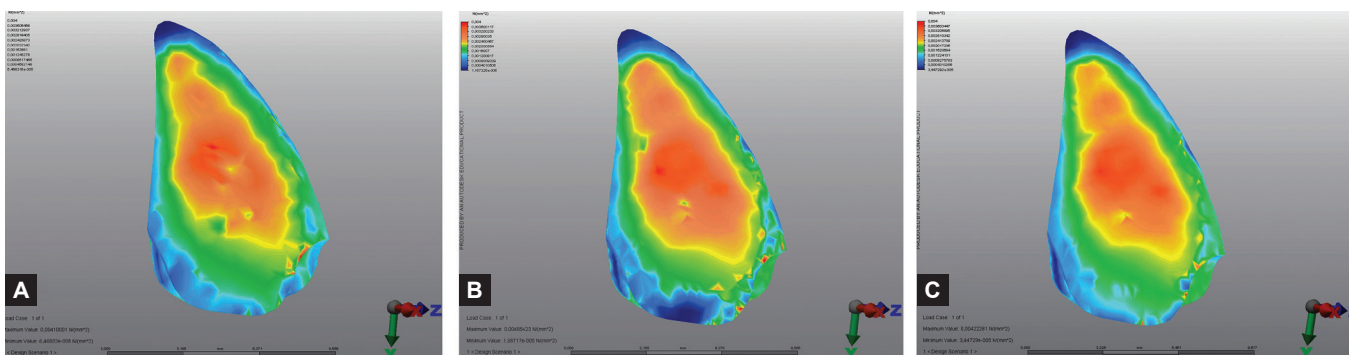
The  $x$ ,  $y$  and  $z$  axes were used as the references for the interpretation of the results. The  $xy$  axes represent the sagittal plane, the  $yz$  axes represent the frontal plane and the  $xz$  axes represent the transverse plane. The results of the simulations were the following.

### Mesial Face

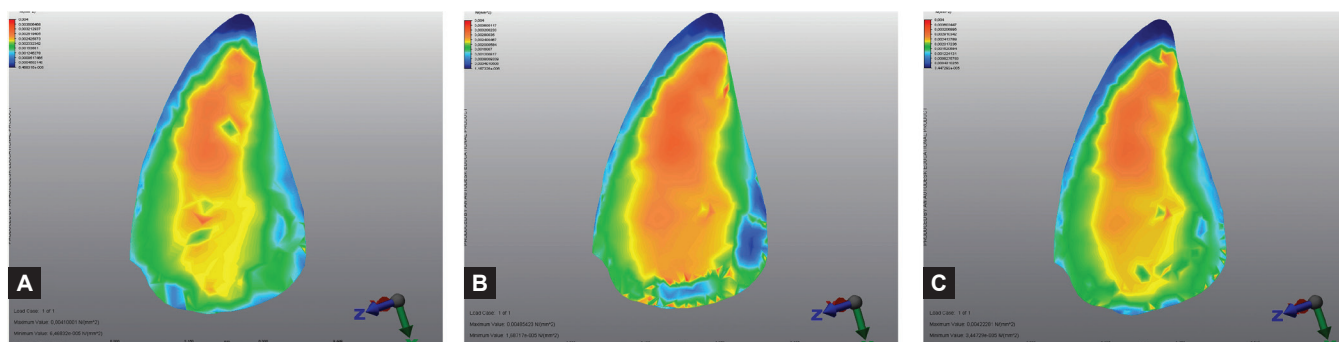
The mesial face of the PDL corresponded to the traction side. The high stress distribution was in the middle third in all of the assessed models, as indicated by the red coloration in this area. The lower stress distribution was present in the apex portion of the PDL; however, the distribution patterns were similar in all test models (Figs 3A to C), which indicated no difference



**Figs 2A to C:** Test models. (A) The control model. (B) The box-shaped corticotomy. (C) The circular corticotomy



**Figs 3A to C:** Stress distribution on the mesial face of the periodontal ligament (A) No corticotomy, (B) box-shaped corticotomy, and (C) circle-shaped corticotomy



**Figs 4A to C:** Stress distribution on the distal face of the periodontal ligament (A) No corticotomy, (B) boxshaped corticotomy, and (C) circle-shaped corticotomy

between them. The stress distribution was uniform along the PDL.

### Distal Face

The distal face corresponded to the compression side of the PDL. The stress distribution pattern was uniform and similar in all test models: the middle third was red, which suggested a high stress distribution, and the apical portion of the PDL was blue, which suggested a low stress distribution (Figs 4A to C).

The stress distribution pattern was uniform and similar in all test models: the middle third was red, which suggested a high stress distribution (and represented the maximum value when the force was initially applied), and the apical portion of the PDL was blue, which suggested a low stress distribution (Figs 3A to C and Figs 4A to C). The values for maximum stress were similar in all test models (Table 2). Therefore, there was no difference between the models when the force was applied to the power arm during canine retraction.

### DISCUSSION

Finite element method is a useful mathematical tool for evaluating the mechanical behavior of tissues. This tool is derived from the engineering field and uses mathematical models to evaluate stress and/or strain fields on geometric bodies that are subjected to loads and/or displacement.<sup>27-29</sup> This property makes the FEM dependent on the correct characterization of the mechanical properties of the geometric model and application of boundary conditions of the problem under study.<sup>25,26</sup>

The mineralized portion of cortical bone has transverse isotropic behavior. However, when it is associated with

soft tissues such as vessels and nerves, the bone matrix is influenced by the liquid part, which gives an anisotropic property to the bone. The present study considered the bone as a homogeneous and isotropic material. The bone and PDL was considered isotropic with linear behavior, according to other studies.<sup>25,26</sup> The anisotropy of the PDL should be carefully considered because these characteristics change the values of Young's modulus and Poisson's ratio.<sup>5,14,30,31</sup> This may be a limiting factor in our study.

In adult patients, canine retraction is an important factor when considering the treatment time because OTM occurs at a rate of 1 to 2 mm per month. Studies have shown that canines full retraction could take up to 8 months.<sup>12,13</sup> Studies have focused on how to produce a more bodily canine movement and examined whether new technologies can make any difference in decreasing the distalization of the canine and overall treatment time.<sup>32-36</sup> A previous study by Ammar et al<sup>25</sup> showed that the application of the load on the power arm of an Andrews T2 bracket places the force near the canine's center of resistance resulting in a more uniform stress distribution in the PDL and a translational movement; the present study is in accordance with these results. The tension and compression faces of the PDL presented this behavior, where the Andrews bracket was used.

Also, in the present study, the lower stress sites on the PDL were observed in the apex and cervical third; this result is interesting, because one of the most observed complications during canine retraction is crown tipping, and the higher stress sites should be observed near these locations;<sup>35</sup> this study shows a uniform stress distribution, which could imply less hyalinized areas on the PDL and a faster OTM.

A 150-gf load for canine distalization was used as in a previous clinical study that performed corticotomy for canine retraction.<sup>24</sup> Applying this amount of force to the test model produced the desired distribution in all models. No model presented excessive red coloration (Figs 3A to C and Figs 4A to C). The amount of force needed to distalize

**Table 2:** The maximum von Mises stress values

Test models	Maximum von Mises stress (kPa)
A (Control)	4.10
B (Box)	4.07
C (Circular)	4.22

the canines may vary, depending on the PDL form and level.<sup>37</sup> The same situation was observed during rotation movement with stresses concentrated at the apex; hence, due to the concentration of the compressive forces at the apex, a clinician must avoid placing heavy stresses during tooth movement.<sup>38</sup>

How corticotomy increases OTM rates has been explained from a cellular point of view in which inflammatory cells react to bone injury and thereby increase bone turnover.<sup>7,39</sup> Another explanation is that corticotomy accelerates OTM because of decreased bone resistance.<sup>8</sup> In the present study, we expected to see differences between the models; as the rigidity of the trabecular bone was diminished, the corticotomies were performed to determine from a mechanical point of view whether they altered the stress distribution on the PDL in comparison to a test model without an osteotomy procedure.

There were no differences between the test models with corticotomy and the control model. This finding is in agreement with the study of Wilcko et al<sup>11</sup> who showed that the format of the perforations in the corticotomies had no influence on the outcome. The kPa values in Table 2 are all very similar to each other. In the present study, the mechanical decrease in bone resistance produced by the corticotomy procedure was insufficient to cause differences in stress distribution between all test models. This result may be achieved by increasing the number of incisions in different places or by producing more invasive injury to the bone.<sup>39</sup>

## CONCLUSION

From a mechanical point of view, the FEM showed that different corticotomy formats for accelerated orthodontic movement did not affect the distribution of stress in the PDL during canine retraction in the present test models.

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