Andomar Bruno Fernandes Vilela

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Dissertação apresentada à Faculdade de Odontologia da Universidade Federal de Uberlândia como requisito parcial para obtenção do título de Mestre em Odontologia na Área de Clínica Odontológica Integrada.

Uberlândia,

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Orientador: Prof. Dr. Carlos José Soares

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Prof. Dr. Carlos José Soares - UFU
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Ata da defesa de DISSERTAÇÃO DE MESTRADO junto ao Programa de Pós-graduação em Odontologia, Faculdade de Odontologia da Universidade Federal de Uberlândia.

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Título do Trabalho: **Biomecânica do traumatismo em dentes decíduos e permanentes e os efeitos nas estruturas adjacentes: Análise dinâmica não-linear por elementos finitos**.
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As **quatorze** horas do dia **nove de fevereiro do ano de 2018** no Anfiteatro do Bloco 4L, Campus Umuarama da Universidade Federal de Uberlândia, reuniu-se a Banca Examinadora, designada pelo Colegiado do Programa de Pós-graduação em janeiro 2018 , assim composta: Professores Doutores: Guilherme de Araújo Almeida (UFU); Mariane Cardoso (UFSC); e Carlos José Soares (UFU) orientador(a) do(a) candidato(a) **Andomar Bruno Fernandes Vilela.** Ressalta-se que o Prof. Dra. Mariane Cardoso participou da defesa por meio de Videoconferência na cidade de Florianópolis-SC e os demais membros da banca e o aluno(a) participaram *in loco*.

Iniciando os trabalhos o(a) presidente da mesa Dr. Carlos José Soares apresentou a Comissão Examinadora e o candidato(a), agradeceu a presença do público, e concedeu ao Discente a palavra para a exposição do seu trabalho. A duração da apresentação do Discente e o tempo de argüição e resposta foram conforme as normas do Programa.

A seguir o senhor (a) presidente concedeu a palavra, pela ordem sucessivamente, aos (às) examinadores (as), que passaram a argüir o (a) candidato (a). Após a argüição, que se desenvolveu dentro dos termos regimentais, a Banca, em sessão secreta, atribuiu os conceitos finais.

Em face do resultado obtido, a Banca Examinadora considerou o (a) candidato(a) A provado(a).

Esta defesa de Dissertação de Mestrado Acadêmico é parte dos requisitos necessários à obtenção do título de Mestre. O competente diploma será expedido após cumprimento dos demais requisitos, conforme as normas do Programa, a legislação pertinente e a regulamentação interna da UFU.

Nada mais havendo a tratar foram encerrados os trabalhos às 17 horas e 30 minutos. Foi lavrada a presente ata que após lida e achada conforme foi assinada pela Banca Examinadora.

Prof. Dr. Guilherme de Araújo Almeida (UFU)

Profª Drª Mariane Cardoso (USP)

Prof. Dr. Carlos José Soares– UFU
Orientador (a)

DEDICATÓRIAS

À Deus,

Que me ilumina diariamente, que me permitiu chegar até aqui, me deu oportunidades, colocou as pessoas certas em meu caminho e fez todas as coisas em seu tempo, que é o tempo certo.

À minha mãe, Tânia,

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Ao professor Carlos José Soares,

Professor, eu me sinto honrado de ter sido seu aluno nesses últimos dois anos. Você é um exemplo para mim. É um exemplo de que a perseverança, estudo e trabalho duro podem realizar sonhos. Desde a primeira conversa você sempre me incentivou nesse sonho, mesmo sem me conhecer, e eu sou muito grato por isso. Você me deu oportunidades que eu nunca tive, me abriu portas que nunca foram abertas e me ensina diariamente, mesmo nas pequenas coisas. Aprendi muito mais do que ciência, aprendi a ser mais humano. Você tem um coração enorme professor, e por muitas vezes, já te vi priorizar ajudar os outros, seja um aluno, um paciente ou um colega de trabalho. Você é uma inspiração para todos os seus alunos, e eu admiro muito a sua dedicação à Odontologia, à ciência e à sua família. Acredito que sempre devemos enaltecer as pessoas que nos deram oportunidades, assim como você faz em suas aulas, portanto espero um dia poder levar o seu nome aos meus futuros alunos. Todo mundo se espelha em alguém para alcançar seus sonhos e eu me espelho em você. Obrigado por tudo.

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Local onde realizei todo o meu trabalho, minha segunda casa.

EPÍGRAFE

"Work hard, be kind, and amazing things will happen."

(Conan O'Brien)

SUMÁRIO

LISTA DE ABREVIATURAS E SIGLAS

% - Porcentagem

μS – Unidade de microdeformação (microstrain)

et al. – E colaboradores

mm – Unidade de comprimento (milímetro)

N – Unidade de medida de força

MPa – Força/área (Mega Paschoal)

N – Unidade de pressão – carga aplicada (Newton)

mm – Unidade de medida (milímetro)

2D – Bidimensional

3D – Tridimensional

S – Unidade de tempo (segundo)

EVA – Etileno Vinil Acetato (Material utilizado para confecção do protetor bucal)

DICOM – Digital Imaging and Communication in Medicine

STL – Stereo Lithography

ASTM – American Society for Testing Materials

UFU – Universidade Federal de Uberlândia

FOUFU – Faculdade de Odontologia da Universidade Federal de Uberlândia

RESUMO

RESUMO

O trauma dental em dentes decíduos e permanentes pode causar diversas injúrias ao complexo dento-alveolar, no entanto, seu efeito em regiões adjacentes ao impacto como o germe do dente permanente em crianças e as possíveis complicações em dentes adjacentes ainda é ainda pouco conhecido. Este estudo foi desenvolvido por meio de dois objetivos: **Objetivo 1.** Avaliar a distribuição de tensões nos dentes adjacentes ao incisivo central superior que sofreu impacto frontal, a fim de identificar possível explicação para ocorrência de reabsorção radicular em dentes adjacentes que não foram envolvidos diretamente no trauma, evidenciado em um caso clínico tratado na Clínica de Trauma da FOUFU. **Objetivo 2.** Avaliar a distribuição de tensões nos tecidos moles, no tecido ósseo e no germe do dente permanente causadas por traumatismo dental em duas direções envolvendo incisivo central superior decíduo em três estágios de reabsorção radicular fisiológica. O método experimental utilizado foi a análise dinâmica não-linear de impacto por elementos finitos, no objetivo 1 envolvendo modelos 3D e impacto com objeto rígido metálico; e no objetivo 2 envolvendo modelos 2D com impacto da criança em asfalto. Como critérios de pós-processamento para análise de tensões foram os critérios von Mises de von Mises Modificado (MPa) e ainda a deformação (μS) nas estruturas dentais e de suporte. Frente aos resultados concluiu-se que o impacto no dente permanente evidenciou considerável concentração de tensões nas regiões vestibular e palatina da porção radicular dos incisivos adjacentes ao dente traumatizado. As áreas comprimidas foram também verificadas nas regiões proximais das raízes dos dentes adjacentes. O impacto no dente traumatizado causou deformação nos incisivo central esquerdo e lateral direito adjacentes ao dente que sofreu o impacto. Já no objetivo 2, os resultados demonstram que o impacto em incisivo decíduo resultou em tensões significativas no tecido ósseo e tecidos moles circundantes e em menor intensidade no germe do dente permanente, independente da direção do impacto ou do estágio de reabsorção radicular fisiológica. Quanto maior a reabsorção fisiológica do dente decíduo, menores serão as tensões na estrutura óssea e tecido mole circundantes durante o impacto. O impacto na borda incisal na direção axial ao longo eixo do dente decíduo resultou em maior concentração de tensões no osso e tecido mole circundante, independente do estágio de reabsorção fisiológica radicular. As tensões concentradas no ápice do modelo com raiz completa do dente decíduo podem explicar a causa de compressão dos vasos sanguíneos e nervo, o que pode explicar a inflamação/infecção pulpar do incisivo decíduo e consequentemente dos tecidos periapicais.

Palavras-chave: Dentição decídua; germe dentário; trauma dental; distribuição de tensões; análise por elementos finitos.

ABSTRACT

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Dental trauma in primary and permanent maxillary incisors can cause various injuries on the dentoalveolar complex, however, its effect on structures adjacent to the impact as the permanent tooth germ in children and the possible complications to adjacent teeth is still unclear. This study was designed involving two objectives: **Objective 1:** To determine the stress distribution in adjacent teeth to an impacted maxillary central incisor in order to identify possible explanation for root resorption in non-traumatized teeth, similar to the clinical case treated at Dental Trauma Clinical Service at Federal University of Uberlândia. **Objective 2:** To evaluate the stress distribution on surrounding bone/soft tissue and on permanent tooth germ caused by dentoalveolar trauma in primary central incisor with three stages of physiological root resorption. The experimental method used was the nonlinear dynamic impact finite element, involving on the objective 1 the 3D models of impact with rigid metallic object and on the objective 2 involving 2D models of the children reaching the asphalt. For evaluation of the stress distribution were used von Mises and Modified von Mises criteria (MPa), and strain (µS) were evaluated as well. Based on the results it was concluded that the impact on permanent teeth results on considerable stress concentration on buccal and palatal areas of the adjacent root teeth to the traumatized incisor. Compressed areas were also visualized on proximal areas of adjacent root incisors. Considerable deformation was also observed on the lateral and central root incisors adjacent to the traumatic impacted tooth. Based on the results of the objective 2, the impact on the primary tooth resulted on stress concentration on surrounding bone/soft tissue and, in lower intensity, on permanent tooth germ, regardless of the direction of impact and the primary tooth resorption stage. Greater the physiological root resorption of primary tooth, lower is the stresses on the surrounding bone/soft tissue during the impact. The impact on the incisal edge resulted in higher stresses in the permanent tooth germ and on surrounding bone/soft tissue regardless of physiological root resorption stage. Stress concentrated at the primary incisor apex on model with complete root, which cause the compression of the blood vessels and nerves, can explain the generation of pulpal inflammation/infection of a primary tooth and consequences on periradicular tissues.

Keywords: Primary teeth; tooth germ; dental trauma; root resorption; stress; strain; finite element analysis.

INTRODUÇÃO E REFERENCIAL TEÓRICO

1. INTRODUÇÃO E REFERENCIAL TEÓRICO

O traumatismo dento-alveolar em dentes decíduos e permanentes é um evento frequente e que pode causar diversos danos ao dente traumatizado e às estruturas dento-alveolares adjacentes (Saoud *et al*., 2016). Entre as sequelas mais comuns decorrentes do traumatismo dento-alveolar nos dentes permanentes estão a necrose pulpar, reabsorção radicular e anquilose no dente que sofreu injúria do impacto. Isto pode ser explicado devido ao dano físico às células do ligamento periodontal e ao feixe vásculo-nervoso pulpar (Cvek, 1992). Estas sequelas ocorrem quando as camadas de pré-cemento e pré-dentina são danificadas e bactérias provenientes do interior do canal entram em contato com o meio externo, desencadeando assim a inflamação pulpar ou periodontal que pode induzir a reabsorção radicular/anquilose (Fuss *et al*., 2003, Mavridou *et al*., 2017, Patel *et al*., 2010). Por mais que os mecanismos responsáveis pela reabsorção radicular e anquilose ainda não sejam totalmente compreendidos (Gold & Hasselgren, 1992), o traumatismo dento-alveolar é considerado um fator predisponente (Heithersay *et al*., 1999). Na dentição decídua, as possíveis sequelas do impacto são semelhantes, sendo a necrose pulpar e a reabsorção radicular dos dentes decíduos as mais comuns (Lauridsen *et al*., 2017). No entanto, como o dente decíduo tem proximidade com estrutura nobre que é o germe do dente permanente, quando o traumatismo dento-alveolar envolve incisivos decíduos, podem ocorrer complicações futuras que podem ser imperceptíveis até a irrupção do dente permanente (do Espírito Santo Jácomo & Campos, 2009).

A maioria das injúrias dentais envolvem os dentes superiores devido à sua posição mais anterior na cavidade oral, e na sua grande maioria, os incisivos centrais superiores são os dentes mais acometidos, seja na dentição decídua ou na permanente (Zhang *et al*., 2014). Estudos relatam que a prevalência do traumatismo dento-alveolar em dentes permanentes geralmente atinge uma a cada cinco pessoas (20%). No entanto este valor pode chegar a 30,5%, dependendo da região e população avaliada (Adekoya-Sofowora *et al*., 2009 Schatz *et al*., 2013; Schuch *et al*., 2013; Goettems *et al*., 2014; Lam *et al*., 2016; Bonfim *et al*., 2017). Crianças são bastante propensas a sofrer algum tipo de traumatismo dento-alveolar (Lam *et al*., 2008; Chan *et al*., 2011; Mahmoodi *et al*., 2015). Em crianças com dentição decídua na faixa etária entre 0 a 6 anos este valor pode variar entre 10,4% a 36,8%. A prevalência mais comum relatada envolve uma a cada três crianças que sofrem alguma injúria devido ao traumatismo dento-alveolar (Kramer *et al*., 2003; Granville-Garcia *et al*., 2006; ElKarmi *et al*., 2015; Lam *et al*., 2016; Tello *et al*., 2016). Este cenário configura atualmente a premissa de que o trauma dental é uma das principais causas de consultas odontológicas pediátricas (Glendor *et al*., 2008).

Quando o trauma envolve a região anterior, na grande maioria dos casos afeta somente um dente (Schatz *et al*., 2013). Porém, verifica-se na literatura em relatos de casos clínicos, uma possível correlação entre o impacto em um único dente ou grupo de dentes e complicações como necrose pulpar e reabsorção radicular nos dentes adjacentes que não foram diretamente afetados pelo trauma (Aas & Skaare 2011, Santiago *et al*., 2015, Şermet Elbay *et al*., 2015). Lesões severas como avulsão (Chappuis & Von Arx, 2005) ou intrusão (Fuss *et al*., 2003) são provocadas geralmente durante um traumatismo dento-alveolar, com direção do impacto axialmente à borda incisal (Patterson & Popowics, 2014). Estas são as injúrias mais comuns relacionadas ao possível desenvolvimento de reabsorção radicular patológica em dentes permanentes (Chappuis & Von Arx, 2005; Wigen & Agnalt, 2008). Já em impactos frontais, as fraturas de esmalte e dentina são as lesões mais comuns em dentes permanentes (Veríssimo et al., 2016b). Na dentição decídua, as fraturas de esmalte e dentina são incomuns e o impacto frontal pode causar mais frequentemente lesões como a luxação lateral, devido à menor inserção óssea dos decíduos (Lauridsen *et al*., 2017).

É possível relacionar o evento traumático em dentes decíduos com possíveis complicações tardias no dente permanente (Colak *et al*., 2009). A intrusão está entre as injúrias mais relacionadas às possíveis complicações no germe do dente permanente (Lauridsen *et al*., 2017). Injúrias como a avulsão, luxação lateral em dentes decíduos também tem sido relatada como relacionadas à alterações do germe do dente permanente, como hipoplasia, alterações de forma, dilacerações radiculares e lesões brancas/amarelas em esmalte (Da Silva Assunção *et al*., 2009; Lenzi *et al*., 2014; Soares *et al*., 2014). Ademais, infecções de origem pulpar ou anquilose de dentes decíduos também estão relacionadas a possíveis complicações no desenvolvimento do dente permanente (Lauridsen *et al*., 2017). Isso não exclui a possibilidade de que lesões menores, sejam elas em dentes permanentes ou decíduos, possam causar reabsorção radicular ou algum outro dano às estruturas adjacentes (DiAngelis *et al*., 2017). Durante o traumatismo dento-alveolar em dentes decíduos, as resultantes das forças do impacto são propagadas para células da bainha epitelial de Hertwig do germe dente permanente, podendo causar tardiamente, danos às estruturas ao esmalte e dentina (Topouzelis *et al*., 2010).

Sequelas nos dentes decíduos após traumatismo dento-alveolar são diretamente dependentes do estágio de reabsorção radicular fisiológica, levando a diferentes danos de acordo com a extensão radicular remanescente do dente decíduo (Qassem *et al*., 2014). Contudo, a distribuição de tensões e deformações aos dentes adjacentes àqueles dentes permanentes que foram envolvidos no impacto ainda não são claros. Da mesma forma, o efeito da direção do impacto, e o nível de reabsorção fisiológica radicular do dente decícuo envolvido no impacto, na distribuição de tensões e deformação nos tecidos ósseos, tecidos moles e no próprio germe de dente permanente ainda não são conhecidos.

O método de elemento finitos (MEF) é um método matemático que pode calcular por meio de modelos computacionais tensões e deformações em condições complexas. Este método foi desenvolvido na engenharia, sendo utilizado amplamente em diversas áreas do conhecimento. Inicialmente com foco na indústria aeroespacial, o método foi se disseminando para outras áreas de conhecimento com o surgimento dos primeiros softwares comerciais. Este método é considerado como sendo o mais compreensível para calcular a complexa condição da distribuição e propagação de tensões e deformações em diversos materiais e no aparelho estomatognático inclusive odontológicos sob aplicação de carga, proporcionando dados valiosos com custo operacional relativamente baixo e tempo reduzido (Versluis & Versluis-Tantbirojn, 2011; Soares *et al*., 2012). Na odontologia, o potencial da análise por elementos finitos é comprovado em numerosos estudos com análises envolvendo modelos bidimensionais e tridimensionais. Quando se depara com situações nas quais as metodologias tradicionais não conseguem explicar os fenômenos ocorridos, o MEF pode auxiliar a solução destes desafios. Um problema complexo, representado por um modelo virtual é dividido em um número finito de elementos que são conectados por nós. Ao aplicar as propriedades das estruturas e definir condições de contorno é possível, por meio de cálculos matemáticos chegar as deformações e tensões das estruturas externas e internas (Soares *et al*., 2012). No trauma, a simulação não linear e dinâmica, que envolve maior complexidade é fundamental para reproduzir o movimento do impacto e suas resultantes (Veríssimo *et al.,* 2016a).

Portanto, parece oportuno estudar, empregando o MEF, como o traumatismo dento-alveolar pode afetar as estruturas adjacentes ao dente traumatizado. Seja quando o trauma envolve dente permanente e que pode explicar a ocorrência de danos aos dentes vizinhos ao dente que sofreu o impacto. Ou ainda, buscando elucidar quando dentes anteriores decíduos, em diferentes estágios de reabsorção radicular fisiológica, sofrem trauma e os possíveis traumas no germe do dente permanente.

PROPOSIÇÃO

2. PROPOSIÇÃO

Este estudo foi delineado envolvendo dois objetivos específicos que envolvem traumatismo dental buscando por meio do MEF:

Objetivo 1

• Avaliar se as tensões de um impacto podem atingir dentes adjacentes não traumatizados e assim explicar possíveis danos em dentes não traumatizados.

Objetivo 2

• Avaliar o efeito de impacto frontal e axial a incisal de incisivos centrais superiores decíduos com diferentes estágios de reabsorção fisiológica na distribuição de tensões ao tecido ósseo, tecido mole adjacente e ao respectivo germe do dente permanente.

CAPÍTULOS

3.1 Capítulo 1

3D finite element stress analysis of teeth adjacent to a traumatized incisor – Possible cause of resorption in non-traumatized teeth

Delineamento Experimental:

Unidade Experimental: Modelo tridimensional em elementos finitos da maxila e estruturas dento-alveolares envolvendo os seis dentes anteriores.
Fator em estudo: Tipo de força em dois níveis: Impacto Frontal; e Carga mastigatória fisiológica.
Variáveis respostas: Distribuição de tensões e deformação na porção radicular de dentes vizinhos ao incisivo central superior permanente.
Método de análise: Análise dinâmica não-linear por elementos finitos.
Forma de análise dos dados: Avaliação qualitativa da distribuição de tensões.

Artigo a ser enviado para publicação no periódico International Endodontic Journal

3D finite element stress analysis of adjacent teeth to a traumatized incisor – Possible cause of sequelaes in non-traumatized teeth

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Running title: Residual stress causing sequelaes

Keywords: dental trauma, finite element analysis, root resorption, stress distribution.

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3D finite element stress analysis of teeth adjacent to a traumatized incisor – Possible cause of sequelaes in non-traumatized teeth

Abstract

Aim Evaluate the stress distribution at incisors adjacent to an upper central incisor that suffered frontal impact, in order to identify a potential explanation for sequelaes in non-traumatized teeth.

Methodology A 3D finite element model of the maxillary central incisor, lateral incisors and canines was created from a cone-beam scan of a volunteer with normal occlusion. Non-linear dynamic impact analysis was performed, simulating the right central incisor impacted by a steel ball with a velocity of 5 m/s. A functional chewing load (100N) on central incisor palatine was simulated for comparison. Displacements, strains, and modified von Mises stresses were calculated around the adjacent teeth.

Results During the impact on the central incisor, root displacement was verified on the adjacent teeth. Considerable stress concentrations were observed on palatal and mainly on proximal buccal surface of the adjacent teeth near to the traumatized incisor. The stress magnitude on adjacent teeth was higher than stress calculated when functional biting load was simulated. Compression stress was concentrated on proximal areas of adjacent incisors. High levels of deformation were verified on the root dentin of adjacent teeth during the traumatic event.

Conclusions A frontal impact on an anterior tooth also generated stresses at the roots of adjacent teeth. These stresses may play a role in clinically observed sequelaes of teeth adjacent to traumatized teeth.

Introduction

Traumatic dental injury can cause a variety of damage to teeth and supporting structures, among all sequelaes, pulp necrosis, root resorption and ankylosis are the most common complications (Saoud *et al.* 2016). This can be explained due to the physical damage to the periodontal ligament (PDL) cells and pulp blood supply (Cvek 1992), resulting in pulp necrosis and a further loss of cementum and dentin (Andreasen & Bakland 2008). If protective cementum and predentin layers are damaged and intracanal bacteria can enter, an inflammation of pulp or periodontium may induce root resorption/ankylosis (Fuss *et al.* 2003, Mavridou *et al.* 2017, Patel *et al.* 2010). Although the exact mechanisms responsible for root resorption and ankylosis are not fully understood (Gold & Hasselgren 1992), dental trauma is considered a predisposing factor (Heithersay *et al.* 1999).

The majority of dental injuries involve the anterior teeth (Lauridsen *et al.* 2012) and usually may affect only a single tooth that suffered the impact. However, pulp necrosis and root resorption have been observed to develop in adjacent teeth that were not directly impacted (Aas & Skaare 2011, Santiago *et al.* 2015, Şermet Elbay *et al.* 2015). It has been reported that even when pulp response after trauma was positive, complications could develop after several weeks (Aas & Skaare 2011, Şermet Elbay *et al.* 2015). These complications are frequently missed because they remain little understood.

The finite element analysis is a widespread method that can calculate stresses and strains under load application on complex structures through computational models. Due to the impossibility of a traumatic event be tested in situ (Verissimo *et al*. 2016), the finite element analysis seems to be an excellent method that can predict possible areas of structural failure (Rodrigues *et al*. 2017). This method can also explain same biological phenomes that has direct interconnection with biomechanics consequences (Linsuwanont *et al.* 2008)

It is not completely understood the cause of root resorption of the non-traumatized teeth, but this study speculated that the impact involving the right central incisor could have caused stress propagation at the root surfaces of the adjacent teeth. If stresses generated during an impact event can induce conditions for the primary trauma, it is conceivable that impact stresses were also involved in the root resorption at the adjacent teeth. Therefore, the aim of this study was to evaluate deformations and stresses generated around teeth adjacent to a maxillary permanent central incisor that suffers a direct frontal impact using a finite element impact analysis. The null hypothesis tested was that the stresses and strains generated during an impact would not affect adjacent teeth.

Materials and Methods

The current study was prompted by such a case series from our Dental Emergency Trauma Service, where a group of patients reported dental trauma in one tooth and during follow-up examination as radiographic exams, cold pulp vitality and percussion tests were verified pulp necrosis or even initial stages of root resorption on adjacent tooth that was not involved in dental trauma.

A three-dimensional (3D) reconstruction model was created based on a cone-beam tomography image (i-CAT GXCB-500™ Imaging Sciences International, Hatfield, Pennsylvania) of a bank of the images of Dental School, Federal University of Uberlândia. Voxel dimensions were 0.200 mm. A total of 432 slices was obtained with 23 seconds of acquisition and exposure parameters of 120 kV and 5.0 mA.

The cone-beam tomography data were exported in Digital Imaging and Communication in Medicine (DICOM) file format and imported into an interactive medical imaging software (Mimics 18.0, Materialise Dental, Leuven, Belgium). The segmentation of the different structures (compact bone, cancellous bone, enamel and dentin) was accomplished using image density thresholding (Jaecques *et al.* 2004, Pessoa *et al.* 2010). PDL layers (0.2 mm thick) were imposed on tooth roots by Boolean operations. After segmentation, the 3D triangle-based surface of each maxillary structure was exported in Stereo Lithography (STL) format (Figure 1).

The STL surface models were imported and meshed in MSC.Patran® 2010 (MSC.Software, MSC software, Santa Ana, CA, USA) with tetrahedral elements. The created volumetric element mesh was imported into a finite element analysis (FEA) software package (MSC.Marc/Mentat; MSC.Software) to perform the structural analysis (Figure 2).

All materials were considered linear-elastic, isotropic, and homogeneous. The applied material properties (elastic modulus, Poisson's ratio, and density) were obtained from the literature (Table 1). Interfaces between the different tissues were considered bonded. The bone structure was rigidly fixed in the x-, y- and z-directions at lateral cut sections of the maxilla. A dynamic impact analysis was performed using the Single-Step Houbolt method, which is recommended for implicit dynamic contact analyses (Chung & Hulbert 1994), following the method described by Veríssimo *et al.* 2016. An impact object (steel ball with 10mm radius) was simulated to collide with the central incisor at a velocity of 5 m/s (Figure 2). For comparison with functional bite loading, a 100N nodal load applied on palatal surface of the right central incisor. Displacements, strains, and stresses by modified von Mises were recorded in all structures during the impact.

Results

Maximum displacements (mm) and stresses (MPa), at the peak of impact, are visualized in Fig. 3 using a linear colour scale, where blue indicates low values and yellow high values. The incisal edge of the tooth that was impacted shows most displacement, but adjacent teeth can also be seen moving, even though they were not impacted directly (Fig. 3A). The corresponding modified von Mises stress distributions in the tooth and bone structures are shown in Figs. 3B-D. Note that the modified von Mises is an equivalent stress based on the well-known von Mises criterion, but adjusted to take the difference between compressive and tensile strength into account. The bone structure around the traumatized tooth had the highest stress concentration at the middle third of the root (Fig. 3B). The central and lateral incisors adjacent to the traumatized tooth (Figs. 3C-D) showed elevated stress values at the roots mainly at the proximal surface neighbouring the impacted tooth. Stress values on adjacent teeth to the traumatized tooth were approximately 80% lower than the stress calculated on impacted incisor. Stress levels in the root dentin of adjacent teeth during impact were substantially higher (up to 75%) than stress levels when a functional bite loading was simulated (Figs. 3E-F). Third (minimum) principal stresses are shown in Fig. 4, where blue and purple correspond to the highest values of compression. The principal stress distribution shows that proximal root areas were compressed. Microstrains at the buccal root surfaces of the two adjacent incisors during the simulated impact are shown in history plots (Fig. 5). The figure shows that although they were not directly impacted, adjacent teeth were also affected by the traumatic event at the impacted tooth.

Discussion

The null hypothesis was rejected. The residual stresses and strains generated by the impact event affect teeth adjacent to a traumatized tooth. The analysis showed that even areas far away from the impact zone, like the canine, were affected by the propagation of deformation (strain) and consequently stress. Although these strains and stresses were lower than at the directly impacted tooth, they might cause sequelae that turns up later.

This study shows that the lack of correct intra-oral and radiographic examination of adjacent teeth after a traumatic event and the absence of follow-up consultation might be an important factor that can cause sequelae on adjacent teeth, due to it, the clinician should be concerned about the adjacent teeth in order to minimize or even prevent possible sequelae induced by the impact

Deformation and stresses are mediated between teeth and bone by the PDL (Heidary *et al.* 2017). Injury to the PDL is thought to play an important role in mechanisms of tooth trauma and tooth mobility (McCormack *et al.* 2014). Displacement, which was also demonstrated on teeth adjacent to the impacted incisor, can interrupt vascular blood supply and cause pulp necrosis; and it is one of the predisposing factors for root resorption (Aldrigui *et al.* 2013, Lauridsen *et al.* 2016).

In this study, a 100N functional biting load was simulated for comparison with the 5 m/s impact model. When the nodal load was applied on the lingual surface of the incisors, similar to chewing process, the stresses around the adjacent teeth were about 75% lower than during impact. This demonstrated that stress propagated by the impact could contribute in developing sequelae in adjacent teeth as pulp necrosis and root resorption. A small and continuous force on teeth as generated by orthodontic movements can stimulate tissue remodelling (Meikle 2006). However, abrupt and high forces, as occur during dental trauma, may even in low intensity generate an inflammatory process that leads to cellular death, pulpal necrosis and further root resorption (Trope 2002). This study suggests that stress and strain from impact that reach adjacent teeth can initiate/trigger an inflammatory process and potential sequeales.

The computed tomography method used in this study was performed to generate accurate patient-specific maxilla as shown before for bone and surgical studies (Möhlhenrich *et al.* 2017, Lee *et al.* 2017; Rodrigues *et al.* 2017). However, this method implies manual input and needs to be generated, mainly when the radiodensity of different structures on tomography are similar. The FEA model is based on geometric, property and boundary conditions that require assumptions and simplifications. Furthermore, material properties for the oral structures are based on laboratory studies, since it would be impracticable to determine these properties in situ. Dynamic analyses are different from more common static analyses because at high loading rates the inertia forces cannot be neglected. In the current dynamic analysis, we used a method described by Veríssimo *et al.* 2016, where the impact object's velocity and inertia were the initial conditions that determined the time-dependent forces on the tooth models. The validation is always recommended for FEA study, however in this study is not easy to simulate the dynamic impact experimentally. We used functional bite simulation to compare and validate that the stress levels during impact were really higher.

To the best of our knowledge, no study yet has presented an explanation for the trauma at teeth that were not directly impacted. The present study shows that impact stresses also reach the PDL and root surfaces of adjacent teeth, and hence may cause later complications at those teeth. Since the resorption/ankylosis is considered asymptomatic (Fuss *et al.* 2003), it is extremely important that during intraoral and radiographic examination the adjacent teeth are also analysed. It might lead to detection of early stages of sequelaes and allow early implementation of treatment to prevent future tooth loss.

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Figure legends

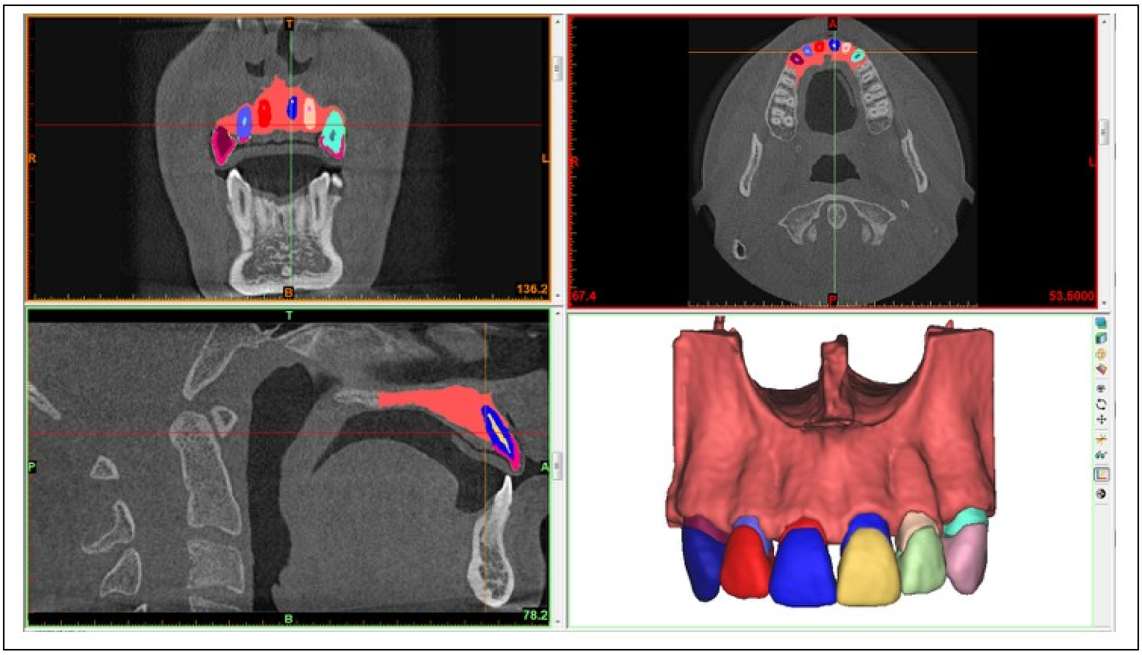

Figure 1. Segmentation of teeh, soft tissues and bone structures obtained by cone-beam tomography using Mimics software (Materialise).

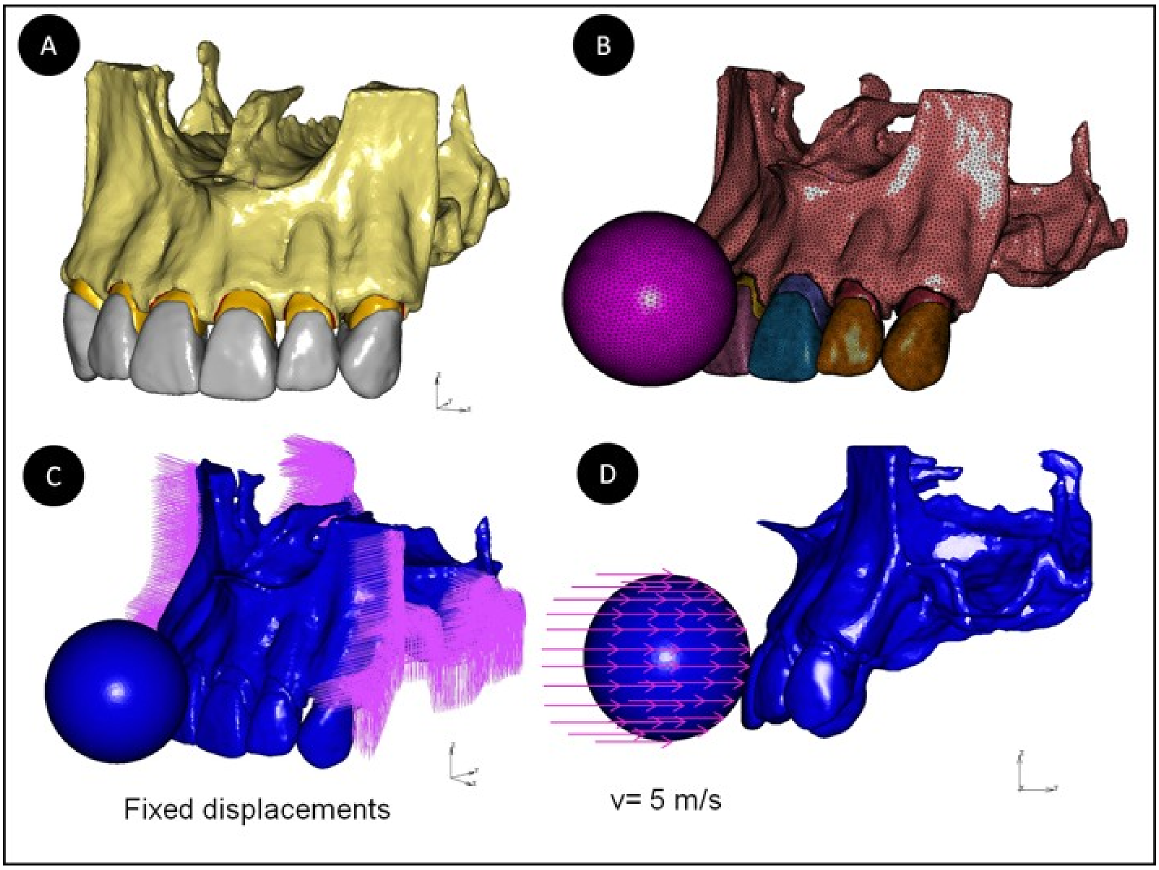

Figure 2. Finite element impact analysis and boundary conditions. A) three-dimensional model B) finite element mesh; C) fixed displacements applied to bone structure; D) applied initial velocity to the impact object.

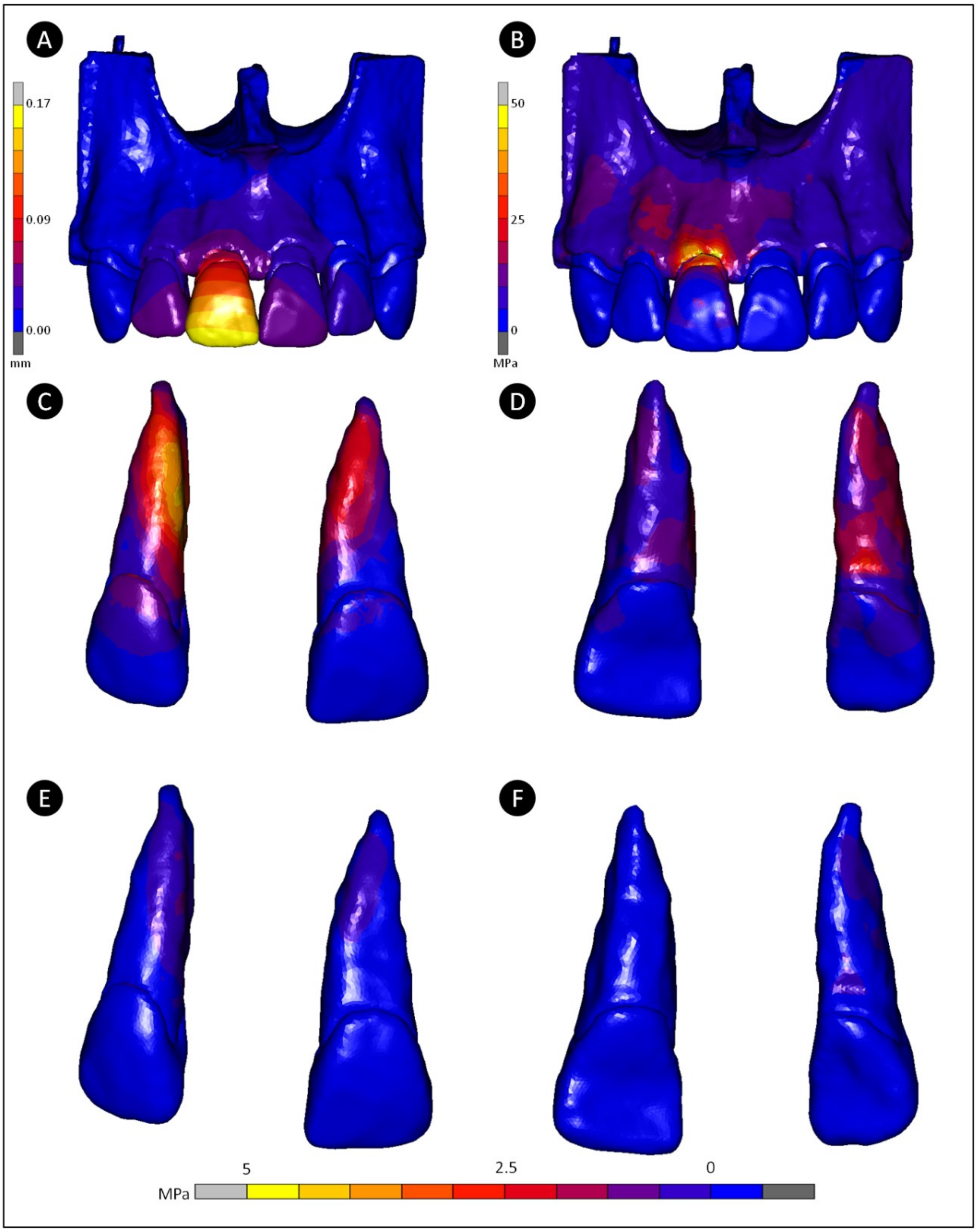

Figure 3. A) Distribution of displacements at the peak of impact on the right central incisor; B) modified von Mises stresses for the maxilla model; C) frontal view; D) palatal view of the teeth adjacent to the incisor that was impacted; E) frontal view and F) palatal view of the modified von Mises stress distributions on teeth adjacent during a chewing simulation.

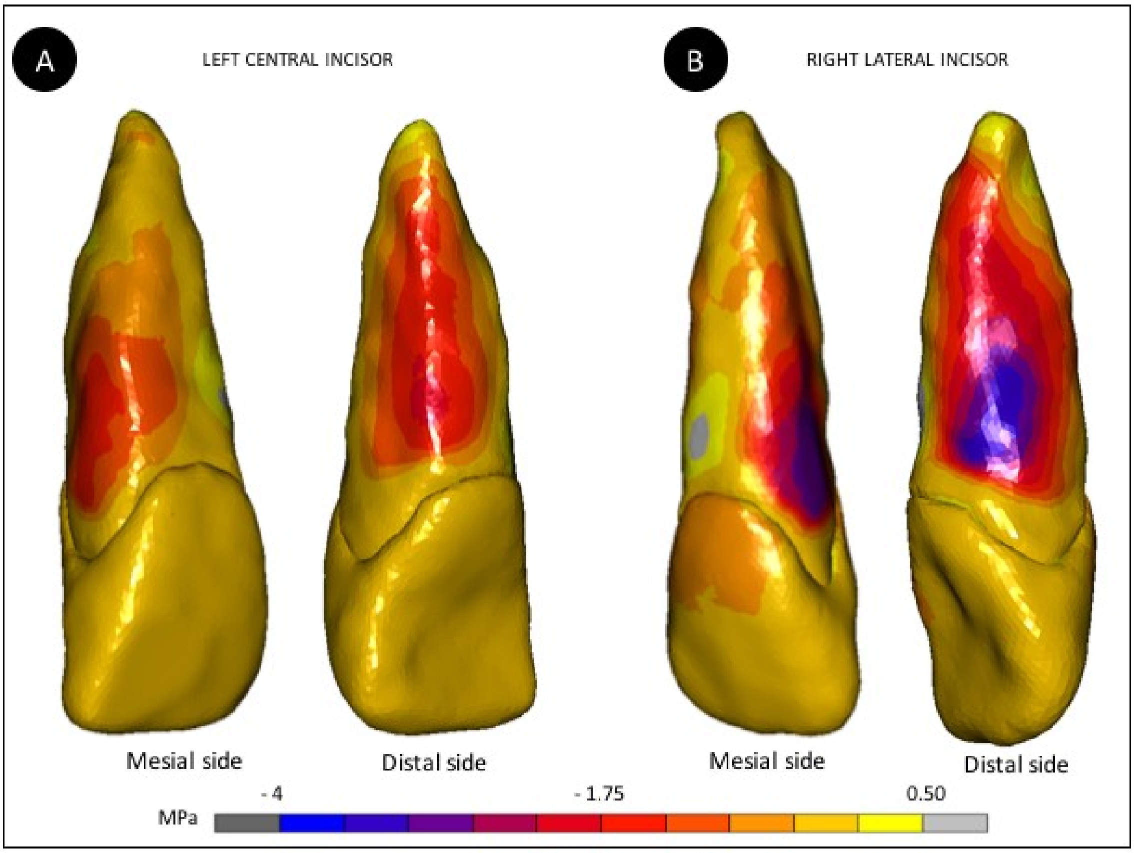

Figure 4. Third (minimum) principal stress distributions on the two adjacent teeth: A) left central incisor and B) right lateral incisor.

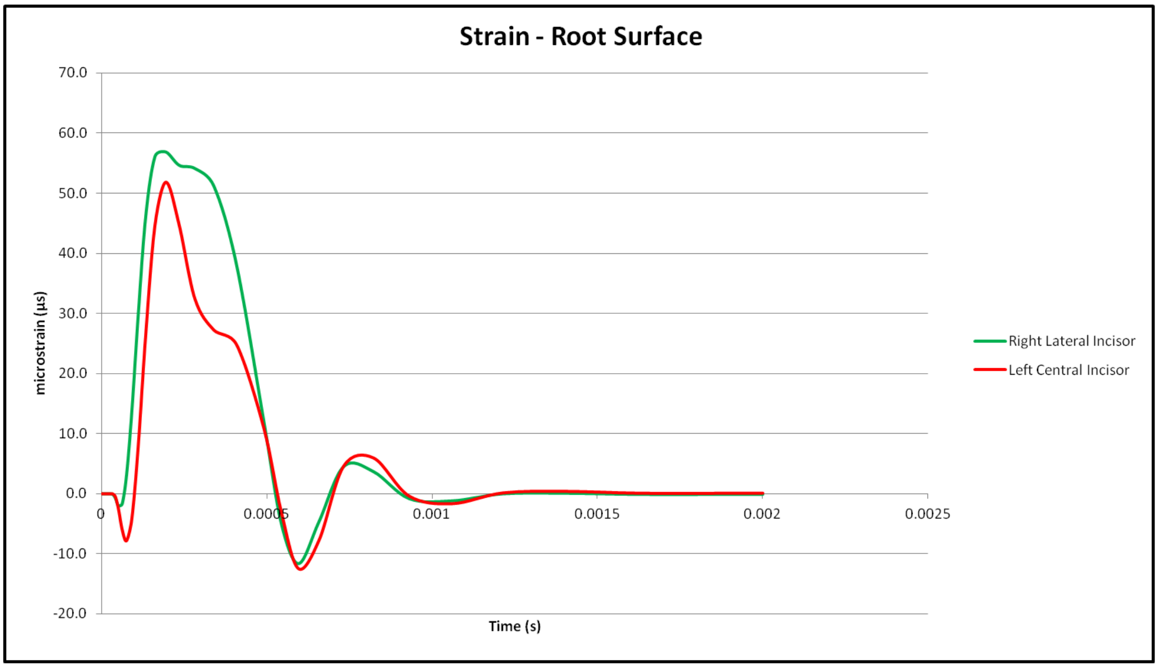

Figure 5. History plot showing the mean of the 10% highest strain values during impact at the buccal side of the root surfaces of the two teeth adjacent to the traumatized incisor.

Table 1. Applied material properties.

Structure	**Elastic Modulus (MPa)**	**Poisson's Ratio**	**Density (g cm $^{-3}$)**	**References**
Enamel	84 100	0.30	2.14	Zarone *et al*., 2006
Dentin	18 600	0.30	2.97	Sano *et al*., 1994
Periodontal ligament	50	0.45	0.95	Rees & Jacobsen, 1997
Cancellous bone	1400	0.31	0.70	Carter & Hayes, 1997
Compact bone	13 700	0.33	2.00	Carter & Hayes, 1997

Steel	200 000	0.30	0.95	ASTM, 2013

3.2 Capítulo 2

Effect of dental trauma on primary tooth with different stages of root resorption on the permanent tooth germ - a dynamic finite element impact analysis

Delineamento experimental:

Unidade Experimental: Modelos em elementos finitos de maxila com incisivo central superior decíduo e germe do dente permanente.
Fatores em estudo:
a) Estágio de reabsorção radicular fisiológica do incisivo decíduo em três níveis:
• Sem reabsorção radicular;
• Reabsorção de menos da metade da raiz;
• Reabsorção de mais da metade da raiz do incisivo.
b) Direção do impacto em dois níveis:
• Impacto frontal;
• Impacto na borda incisal.
Variáveis respostas: Distribuição de tensões, deformação.
Método de análise: Análise dinâmica não-linear por elementos finitos.
Forma de análise dos dados: Avaliação qualitativa da distribuição de tensões.

Artigo a ser enviado para publicação no periódico Dental Traumatology

Effect of dental trauma on primary tooth with different stages of root resorption on the permanent tooth germ - a dynamic finite element impact analysis

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Running title: Trauma on primary incisor and stress on permanent tooth germ.

Keywords: primary tooth, permanent tooth germ, dental trauma, mouthguard, stress distribution, finite element analysis.

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Conflict of Interest Statement

The authors confirm that they have no conflict of interest.

Effect of dental trauma on primary tooth with different stages of root resorption on the permanent tooth germ - a dynamic finite element impact analysis

Abstract

Background/Aim Determine by finite element analysis (FEA) the stress propagation to the permanent tooth germ, and surrounding bone/soft tissues caused by dental trauma on primary central incisor with three levels of physiological root resorption.

Material and Methods Two-dimensional models, simulating three different physiological root resorption stages of a maxillary primary central incisor involving periodontal ligament, bone and soft tissue were created. The impact was simulated in two directions, on the buccal surface and on the incisal edge of primary incisor. A nonlinear dynamic impact analysis was performed between a rigid object and the primary incisor at 1 m s^{-1}. The von Mises stress and strain were evaluated.

Results The impact on primary incisor resulted on stress concentration on surrounding bone/soft tissue and on permanent tooth germ, regardless of the direction of impact and the primary tooth resorption stage. Greater the physiological root resorption of primary tooth, lower is the stresses on dental follicle and surrounding bone tissue during the impact. Incisal impact generated higher stress concentration on surrounding bone/soft tissues and permanent tooth germ regardless of physiological root resorption stage. Stress concentrated at the primary incisor apex (model 1), which cause the compression of the blood vessels and nerves that can explain the generation of pulpal inflammation/infection of a primary tooth and consequences on periradicular tissues.

Conclusion The impact on primary tooth caused expressive stress on permanent tooth germ. The stress concentrated at dental follicle and surrounding bone tissue tend to be more important for causing damage on the formation of the enamel and dentin of the permanent tooth.

INTRODUCTION

Dental trauma is a frequent event on primary teeth and it is one of the mainly causes of pediatric dental consultation (1). Some studies report that the age group between 0 to 7 years old is very prone to suffer dental trauma injury (2, 3, 4). The prevalence of dental trauma in deciduous teeth can reach 35.5% of children at this age (5). The most prevalent teeth to suffer a dental trauma are primary and permanent upper central incisors (6).

The trauma on primary teeth is related to possible complications to permanent tooth (7) and the direction of impact on dental trauma can also be determinant for the type of injury, the impact on incisal edge might cause intrusion injuries (8). Severe intrusion lesions on primary teeth can be related to alterations on the permanent dentition as hypoplasia, shape alterations, root dilacerations and white/yellow spot lesions (9, 10, 11). While in a frontal impact, lateral luxation injuries are the most common lesions (12). Pulp infection/periapical inflammation or ankylosis of deciduous tooth is also associated with possible complications at development of permanent tooth (7). The damage may be caused by the direct trauma of the primary tooth in contact of the permanent germ (8). During a dental trauma injury on primary incisor, the impact can be propagated to the cells of Hertwig's epithelial sheath of permanent tooth germ causing serious damage to permanent germ formation (13).

The determination of the effect caused by trauma on primary tooth on permanent germ tooth and surrounding bone/soft tissues experimentally is difficult or even impossible, by methodologies limitations and ethical implications (14). Finite element analyses (FEA) is a method that can calculate in computational models the stresses and strains of materials under load application (15). In the authors' knowledge, there is no study that associates how the different physiological root resorption stages will affect the stress and strain distribution caused by dental trauma on the permanent tooth germ and surrounding bone/soft tissues. Therefore, the aim of this study was to evaluate by FEA the effect of the impact in different directions on the primary incisor with three levels of physiological root resorption on the stress and strain distribution on permanent tooth germ and surrounding bone/soft tissues. The null hypothesis tested was that the stresses and strains on the surrounding bone/soft tissues and permanent tooth germ generated by the impact would not be affected by the direction of impact or physiological root resorption stage of primary central incisor.

MATERIALS AND METHODS

Three computer cone-beam tomography images of children between 2 to 6 years old with the same occlusal characteristics of the tomographic image bank at School of Dentistry, Federal University of Uberlândia with normal occlusion were used to create the finite element models (Fig. 1A). Two-dimensional (2D) models that involve maxillary primary central incisor, germ of permanent tooth, periodontal ligament, bone (cortical and medullar) and surrounding soft tissue were created. Six models were created including 2 study factors: A. stage of the root resorption of primary incisor, 3 levels: Model 1- No root resorption; Model 2- Less than half the root reabsorbed; Model 3 - More than half the root reabsorbed; and B. Dynamic impact direction, 2 Levels: 1. On the incisal edge axially along to the primary tooth; 2. On the center of buccal surface of the primary incisor, perpendicular along to the primary tooth. Traced tissue outlines of a CT-tomography was exported to a software for input coordinates points (Image J, public domain, National Institute of Health, Bethesda, MD, USA). Coordinates points (Fig. 1B) of the tissue outlines were traced and were imported into a FEA software package (Marc/Mentat, version 2010.2, MSC software, Santa Ana, CA, USA). Cubic-spline curves were made through the obtained coordinates, creating tissues outlines (Fig. 1C). The element mesh was created using four-node isoparametric arbitrary quadrilateral plane-strain elements with reduced integration (one integration point per element, type number 115 in the Marc/Mentat software) (Fig. 1 D).

All interfaces were considered bonded. The dynamic impact was based on Single-Step Houbolt method, which is an algorithm used for implicit dynamic contact analyses (16, 17). A rigid and flat impact object simulating asphalt was created, and a 1.0 m s^{-1} initial velocity was applied to all the nodes of the impact object in both directions. The impact object was unrestrained after this initial velocity was applied and no gravitational forces were modeled. The nodes on top of the bone structure were rigidly fixed in the x- and y-directions (Fig. 1E and F). All materials were considered linear, isotropic, and homogeneous. The mechanical properties of all materials used in this simulation are shown in Table 1.

The models and its different stages of physiological root resorption carry out with two directions of impact are shown on Fig. 2. All models were solved in software Marc/Mentat, and the results were analyzed after impactor lost contact with the teeth. A custom-made subroutine recorded the 10% highest stresses in the permanent enamel and permanent dentin at the tooth germ during the impact and the stress distributions were analyzed using von Mises stresses at the peak of the impact, which integrate all stress components, were used as an indication for the stress energy generated during the impact. The subroutine also determined the strain values for one node on permanent tooth germ at y-direction. Critical von Mises stresses were also evaluated to determine critical areas for structural failure at the impact. This criterion takes the difference between compressive and tensile strengths and scales the equivalent values relative to their tensile strength (critical stress ratio). Tensile and compressive strengths of enamel were 10.3 MPa and 384.0 and for dentin 98.7 and 297.0 MPa, respectively (15).

RESULTS

Stress distributions on the primary incisor, surrounding soft tissues and permanent incisor germ when submitted for all models are shown on Fig. 3 (incisal impact), and on Fig. 4 (frontal impact). The stress values are based on a linear color scale bar, where yellow and light grey represents the highest stress values and blue and dark grey the lowest. The incisal impact (Fig. 3AIV, 3BIV, and 3CIV) resulted in higher stress on permanent germ and on buccal surrounding bone and soft tissue and lower stress on primary incisor than frontal impact (Fig. 4AIV, 4BIV, and 4CIV). The impact on primary tooth generate stress concentrated initially on the primary incisor (Fig. 3I and 4I), then it is transferred to the surrounding bone/soft tissues and, at lower intensity to the permanent tooth germ, regardless of the direction of impact and the primary tooth resorption stage (Fig. 3II-3IV; 4II-4IV). Greater the root of primary tooth, higher are the stresses on traumatized primary incisor (Fig. 3 and 4AIV, BIV and CIV). On the other hand, greater the physiological root resorption of primary tooth, higher are the stresses on surrounding bone tissue (Fig. 3C and Fig. 4C). The dynamic impact direction influenced the stress concentration. The impact on the incisal edge axially along the primary incisor resulted in higher stress than frontal impact on the center of the buccal surface (Fig. 3, 4 and 5).

Stress distributions on the surrounding soft tissues when submitted to incisal impact and frontal impact for all models are shown on Fig. 5. The stress on the dental follicle tissue concentrated along the buccal cortical bone tissue and on the apical area of the lingual cortical bone tissue. Greater the root of primary tooth, higher are the stresses on the dental follicle (Fig. 5 A, B and C). The impact on primary tooth resulted in stress concentration on the permanent tooth germ, regardless of the direction of impact and the primary tooth resorption stage (Fig. 6). The history plots with mean of the 10% highest stresses for permanent enamel and dentin of the permanent tooth germ for incisal and frontal impact, are shown in Fig. 6. The incisal impact on primary incisor with no root resorption (model 1) resulted in 80% the stress on permanent tooth germ and on primary incisor with less than half of the root resorption (model 2) the stress was 62% lower compared to the stress generated by impact with the primary incisor with higher root resorption (model 3). Greater the physiological root resorption of primary tooth, higher are the stresses on permanent tooth germ (Fig. 6A to 6C).

The strain peak values on the permanent tooth germ are shown in the Fig. 7. The incisal impact resulted in higher strain on permanent tooth germ than frontal impact (Fig. 7). The root resorption influenced the strain values, the greater the physiological root resorption of primary tooth, higher are the strain values on permanent tooth germ (Fig. 7 - Model 3).

DISCUSSION

The premise that dental trauma on primary teeth may cause damage on the surrounding bone/soft tissue, and on permanent tooth germ is totally accepted nowadays. However it is not clearly explained how the trauma on different directions involving primary incisors with different root resorption stages if the impact was not sufficient to cause the contact with the permanent tooth germ.

This study used FEA to evaluate the stress and strain using 2D models. The direction of impact and the physiological root resorption stage of primary incisor resulted on different stress/strain concentration on the surrounding bone/soft tissue, and on permanent tooth germ. Therefore, the null hypothesis was rejected. The FEA methodology is considered an important method that can predict stress and strain behavior during impact load through simulation of different structures, which is not easy or possible to test experimentally. Although was created 2D model, it represents a 3D condition that may occur in the cross section of a structure with considerable thickness out of the plane (15). In previous study, it was shown that 2D FEA has similar behavior as observed in an ex vivo impact experiment (14). Therefore, validation of this model was previously tested in similar studies that analyzed the effect of the dynamic impact, the use and thickness of mouthguard (14, 16).

Three stages of the primary tooth simulate in this study involve children with 3.5, 5 and 6 years old. The results of this study demonstrated that even if the impact is not severe that cause contact between root of the primary tooth with the permanent tooth germ, the trauma may cause damage on the permanent tooth.

Dental trauma involving the primary central incisor with different stages of the physiological root resorption, which represent the age of the children, had an important influence on stress and strain propagations to the surrounding bone/soft tissue and permanent tooth germ. The impact on primary incisor with complete root (children with 3.5 years old) resulted in lower stress and strain on permanent tooth germ when compared to the greater root resorption (6 years old). Probably this aspect can be explained by the presence of the cortical bone barrier and dense fibrous tissue between the primary incisor and the permanent tooth germ tooth which is an important natural protection that concentrated higher stress, which means that the complete dental follicle at this age acts protecting the permanent tooth germ (Fig 3 and 4). The presence of only soft tissue between permanent tooth germ and primary incisor on older ages, without bone barrier, can explain the higher propagation of the stresses and strains to permanent tooth germ. The greater root resorption stage is also associated with anterior/posterior expansion of the bone alveolus increasing the volume of the soft tissue; with can explain the highest stress and strain values on permanent germ for model 3 (6 years old). This study showed that the stress generated by trauma can be an explanation for low or medium load impact on primary tooth. Clinically, when the primary incisor with no root resorption suffers trauma, the clinicians tend to have more concern about the damage on the permanent tooth germ. We speculated that the stress concentrated at surrounding bone and on dental follicle, which were higher intensities than those concentrated directly on permanent tooth germ and the stresses on primary tooth itself that might suffer a pulpal necrosis and lead to a periapical infection, tend to be more important for causing damage on the formation of the enamel and dentin of the permanent tooth. The impact forces can be propagated to the cells of Hertwig's epithelial sheath of permanent tooth germ causing serious damage to permanent germ formation (13). The trauma in primary incisor may lead also pulp necrosis and periapical abscess, which can potentialized the environment for damage on the cell formation of the permanent tooth (7). When the primary incisor without root resorption suffered trauma (model 1 – 3.5 years old), the apex of the primary incisor is compressed against the bone barrier (Fig. 1AIV and 2AIV) This is related to fact that traumatic event at younger ages results on more frequent and more severe sequelaes on permanent tooth germ (10). The compression of the blood vessels and nerves can cause pulpal inflammation/infection of a primary tooth and the spread of this condition over the periradicular tissues can lead to alterations in the dental germ of the permanent successor and to the surrounding structures if no therapy is done, i.e. endodontics or extraction (24).

The FEA results showed that the highest stress concentration on the surrounding bone/soft tissue was verified on the model with no physiological root resorption of primary tooth, which occurs at age of 3 years old. In this age, children have poor motor skills and psychomotor underdevelopment, which do not allow the child to perform precise and safe movements and it is the time when the child acquires independence and starts to explore its environment (25, 26). Irrespective of the age the prevalence of dental trauma, this study demonstrated that the stress/strain may be a main cause to explain the complications on the permanent tooth. Trauma to primary tooth leads to abnormal variations in crown and root canals of permanent teeth that presents a challenge in diagnosis and clinical management to the practitioner (27). The stress concentration on the surrounding bone/soft tissue tend are correlate on the area with complications in the root formation process and problems on permanent crown in younger ages, during the crown formation phase (7).

The highest stress/strain was verify on all models where it was simulated the impact on incisal edge of primary tooth. The impact direction vector caused the stresses and they propagated directly to the permanent germ (13). The stress concentration increases on the permanent tooth germ with greater physiological root resorption. Between two to six years old the most common trauma on children are lateral luxation injuries and intrusion injuries (6, 28) and this is directly related to the direction of impact. The frontal impact results in a displacement of the impacted tooth usually in a palatal or labial direction (9); however, when the impact is on incisal edge, results in a compression of the tooth to the dentoalveolar structure, leading in a severe dental trauma as intrusion or lateral luxation (8).

This study evaluated the stress and strain distribution on the primary incisor tooth during different impact directions of different stages of root resorption and has same limitations. A real intrusion of primary tooth on FE models was not simulated. A real intrusion of primary incisor, mainly during a simulated impact on incisal edge of the tooth could add additional information how the intensity of the impact can cause stress and strain on permanent tooth germ. Future studies involving two-dimensional FEA of human maxilla could improve the accuracy of impact analyses. However, this study can really explain the consequences of the lower and medium load impact on the primary incisor. Therefore, the clinicians need to taking into to account the necessity of the continue observation during periodic exams followed the dental trauma, irrespective of the magnitude of the impact and the visible damages.

CONCLUSION

Within the limitations of this study, it can be concluded that the impact on primary tooth caused expressive stress on surrounding bone/soft tissue and lower intensity on the permanent tooth germ. The impact on incisal resulted in higher stresses and strains compared to frontal impact. The primary incisor with no root resorption had the highest stress on the apex of the primary incisor and highest stress on the surrounding bone/soft tissues. The stress concentrated at surrounding bone and soft tissue tend to be more important for causing damage on the formation of the enamel and dentin of the permanent tooth.

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Figure legends

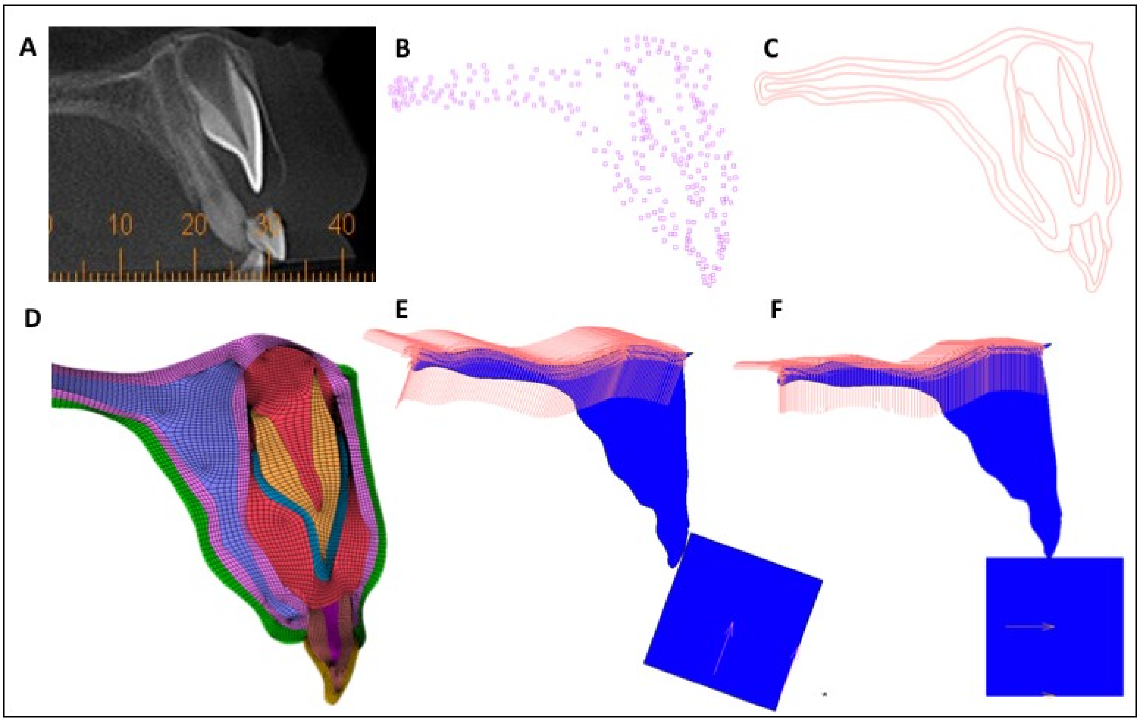

Figure 1. Generation of two-dimensional finite element models. A. CT-tomography image of maxillary primary central incisor with permanent tooth germ; B. coordinates points of the CT image imported from software Image J; C. cubic-spline curves generated from the coordinates; D. finite element mesh generation; E. boundary conditions of frontal impact; F. boundary conditions of incisal impact.

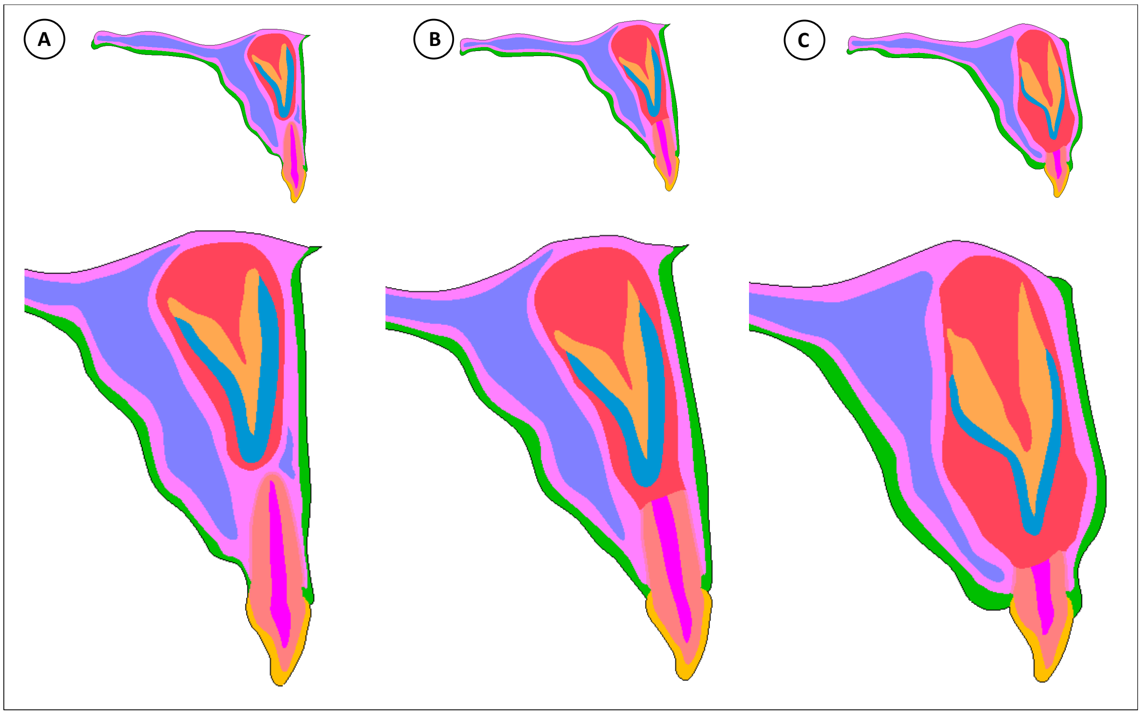

Figure 2. Two-dimensional finite element models. A. Model 1 - No root resorption; B. Model 2 - Less than half the root reabsorbed; C. Model 3 - More than half the root reabsorbed.

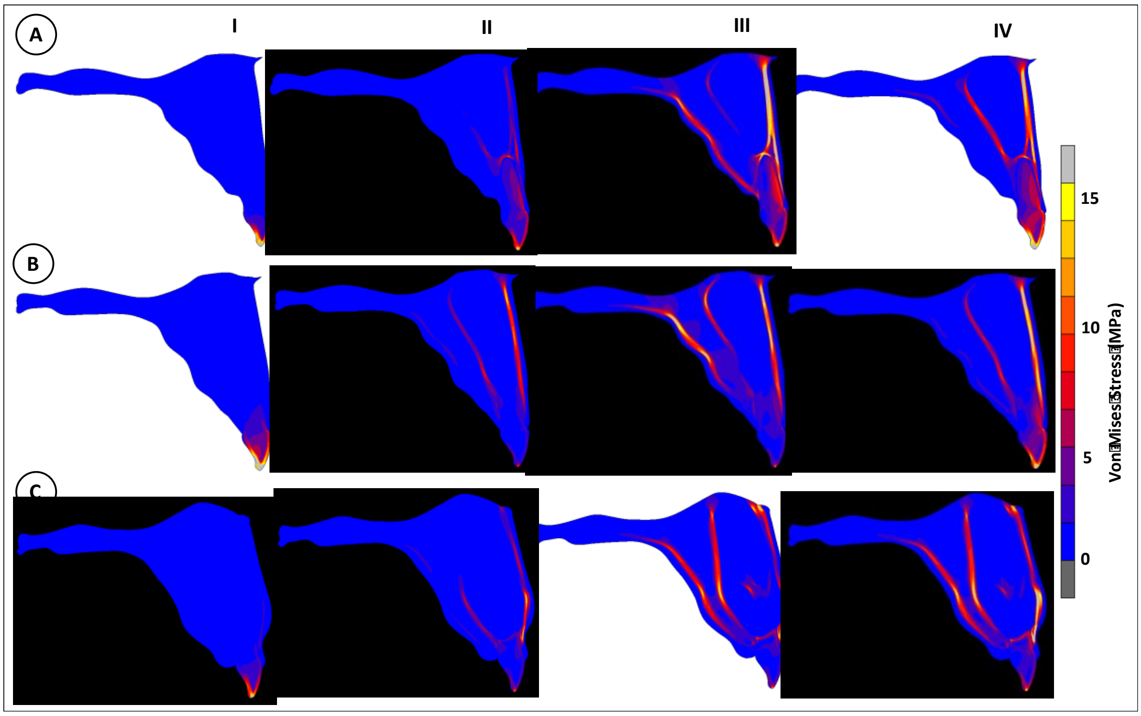

Figure 3. von Mises stress distributions during incisal impact on maxillary primary incisor: I - initial contact with the asphalt; II and III intermediate stages of the stress distribution; IV maximum peak of the stress after impact. A) Model 1; B) Model 2; C) Model 3.

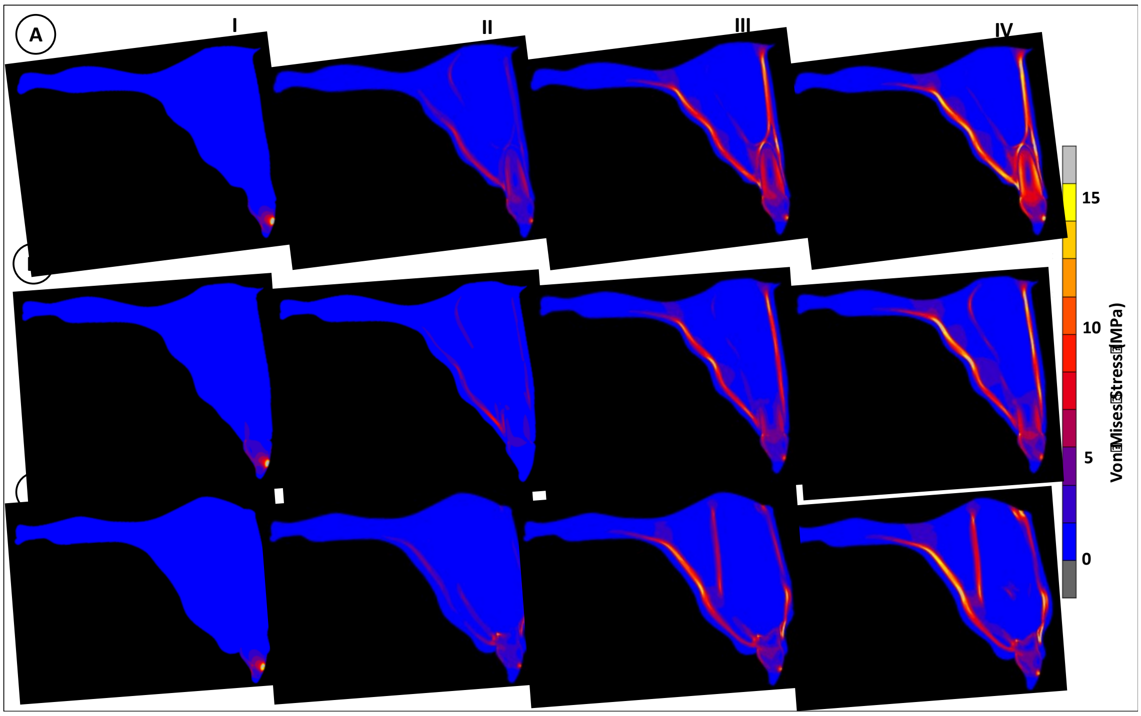

Figure 4. von Mises stress distributions during frontal impact on maxillary primary incisor: I - initial contact with the asphalt; II and III intermediate stages of the stress distribution; IV maximum peak of the stress after impact. A) Model 1; B) Model 2; C) Model 3.

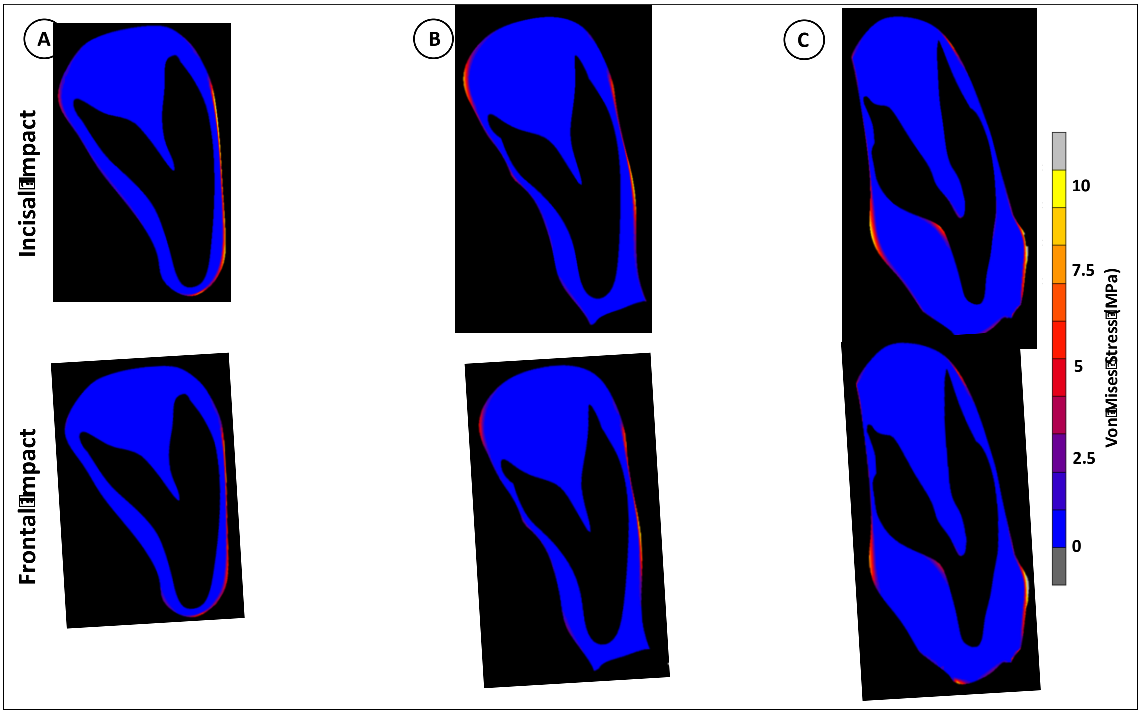

Figure 5. von Mises stress distributions during incisal and frontal impact on surrounding soft tissue: I - initial contact with the asphalt; II and III intermediate stages of the stress distribution; IV maximum peak of the stress after impact. A) Model 1; B) Model 2; C) Model 3.

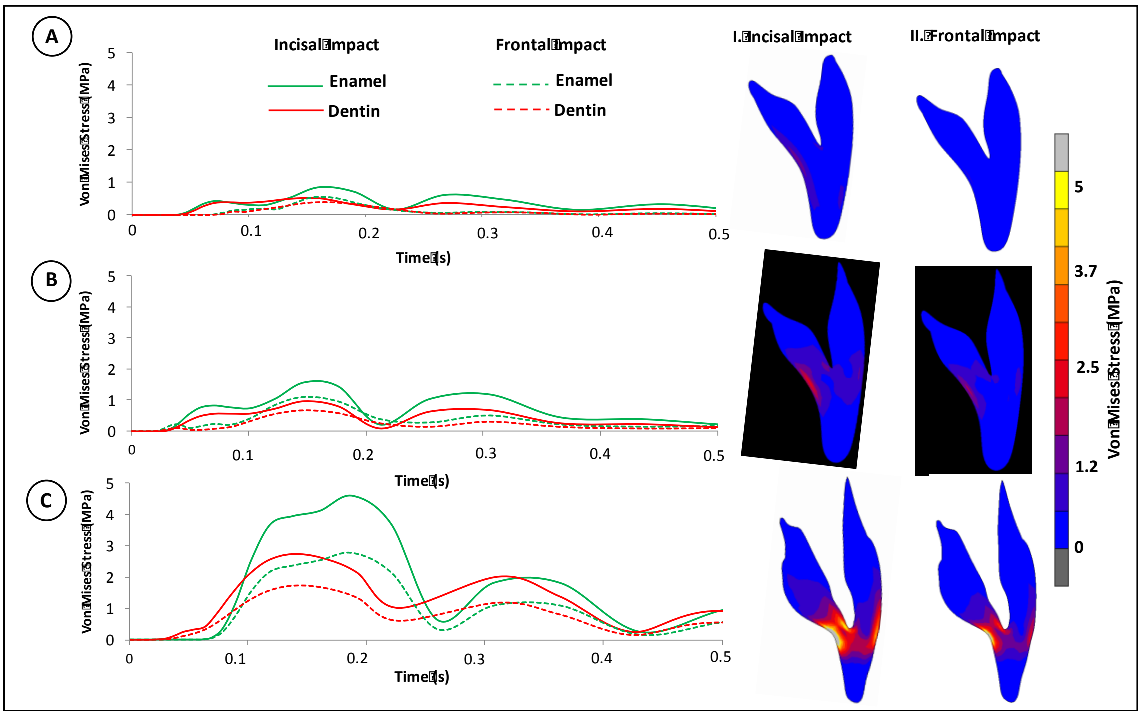

Figure 6. Mean of 10% highest stress values for permanent enamel and permanent dentin during history of the of Incisal and frontal impact. The von Mises stress distribution during I, Frontal impact; II Incisal impact on permanent germ of the central incisor. A, Model 1; B Model 2; C, Model 3.

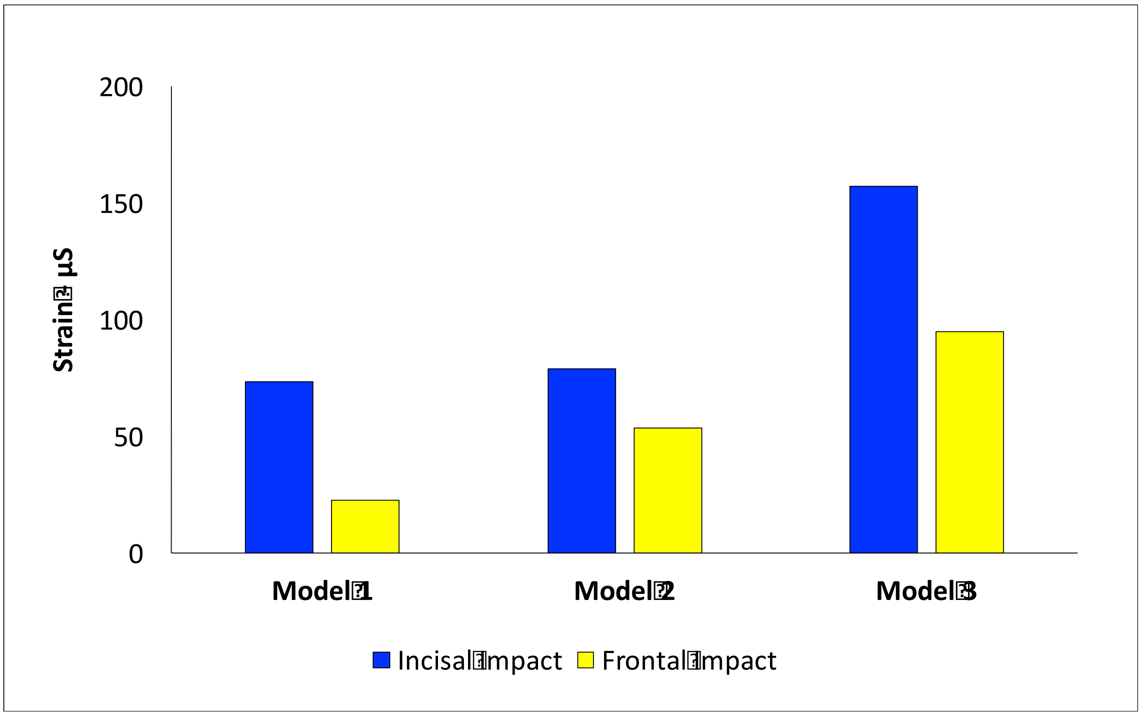

Figure 7. Strain values at the permanent tooth germ for 3 stages of root resorption of impacted primary incisor.

Table 1. Dental structures and material properties.

Structure	Elastic Modulus (MPa)	Poisson's Ratio	Density (g/cm $^{-3}$)	References
Enamel	84 100	0.30	2.14	(18)
Dentin	18 600	0.30	2.97	(19)
Periodontal ligament	50	0.45	0.95	(20)
Trabecular bone	1400	0.31	0.70	(21)
Cortical bone	13 700	0.33	2.00	(21)
Asphalt	56 000	0.32	2.95	(22, 23)

CONSIDERAÇÕES GERAIS

4. CONSIDERAÇÕES GERAIS

Frente as limitações dos delineamentos experimentais estabelecido para os estudos, pode se inferir que:

1. O impacto frontal em incisivos centrais superiores gera tensões, muito acima daquelas geradas por forças de mordidas fisiológicas, na porção radicular de incisivos adjacentes não envolvidos diretamente no trauma. Estas tensões e deformações podem ser fator que explicam situações clínicas nas quais se observam necroses pulpares e reabsorções radiculares em dentes adjacentes a incisivos traumatizados não envolvidos diretamente pelo trauma.

2. É extremamente importante durante a avaliação clínica e radiográfica que se examine os dentes adjacentes ao dente traumatizado. Isso pode viabilizar a detecção de estágios iniciais de reabsorção radicular patológica e permitir a implementação do tratamento para prevenir a perda dentária futura.

3. O impacto em dentes decíduos em diferentes estágios de reabsorção radicular pode resultar em danos ao germe do dente permanente.

4. As tensões concentradas no tecido ósseo e tecidos moles adjacentes ao germe do dente permanente parece ser mais importante na geração de danos ao germe do dente permanente, principalmente quando em estágios iniciais de sua formação.

RELEASE PARA A IMPRENSA

5. **RELEASE PARA A IMPRENSA**

Os traumas dentais são situações de emergência que acometem os dentes, gengiva e o osso, e que se transformam em experiências dramáticas para os pais e para os pacientes. É bastante comum em crianças e adolescentes e pode causar graves lesões na boca podendo gerar prejuízos na mastigação, estéticos e na fala. O traumatismo dental acomete mais de um terço das crianças entre 0 a 6 anos e em adultos envolve uma em cinco pessoas. Este é um tema de importante relevância social a ser estudado devido aos possíveis comprometimentos inesperados que o trauma dental pode ocasionar, seja em crianças com os dentes de leite e suas possíveis complicações no dente permanente ainda em desenvolvimento, ou em pacientes jovens e adultos com dentes permanentes e as implicações nos dentes vizinhos ao dente traumatizado. Por meio deste estudo que simula em computador a queda com trauma dental no asfalto de crianças entre 3 e 6 anos verificou-se que as forças do impacto podem atingir o germe do dente permanente ainda em desenvolvimento no interior do osso. Isso pode gerar alteração do dente permanente como manchas, alterações de forma na coroa e na raiz, gerando implicações futuras quando ocorrer a troca da dentição. Foi verificado também que, o traumatismo dental em adolescente envolvendo o incisivo central superior, (o dente maior da frente) pode propagar forças para os dentes vizinhos, podendo ocasionar complicações nestes dentes, desde necroses pulpares a reabsorções radiculares. Se não tratada, pode causar a perda do elemento dentário. Portanto, é fundamental que caso a criança e adolescente sofra algum tipo de lesão proveniente do traumatismo dental, mesmo que aparentemente simples, o mesmo deve procurar socorro rapidamente. O cirurgião-dentista realizará completo exame clínico e radiográfico, promovendo correto diagnóstico, tratamento da lesão. É importante ressaltar que em todos os casos de traumatismo dento-alveolar é necessário o acompanhamento a médio e longo prazos evitando complicações que possam aparecer.

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