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Área de Concentração: Clínica Odontológica Integrada

Uberlândia

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Área de Concentração: Clínica Odontológica Integrada

Orientador: Prof. Dr. Carlos José Soares
Coorientador: Prof. Dr. Antheunis Versluis – The University of Tennessee Health Science Center

Banca Examinadora:

Prof. Dr. Carlos José Soares - UFU

Profa. Dra. Camilla Christian Gomes Moura - UFU

Profa. Dra. Priscilla Barbosa Ferreira Soares - UFU

Profa. Dra. Marília Leão Goettems - UFPel

Profa. Dra Gabriela Campos Mesquita - UniRV

SUPLENTES

Profa. Fabiana Sodré de Oliveira - UFU

Profa. Renata Afonso da Silva Pereira - Unitri

Uberlândia, 2021

UNIVERSIDADE FEDERAL DE UBERLÂNDIA
Coordenação do Programa de Pós-Graduação em Odontologia
Av. Pará, 1720, Bloco 4L, Anexo B, Sala 35 - Bairro Umuarama, Uberlândia-MG, CEP 38400-902
Telefone: (34) 3225-8115/8108 - www.ppgoufu.com - copod@umuarama.ufu.br

ATA DE DEFESA - PÓS-GRADUAÇÃO

Programa de Pós-Graduação em:	Odontologia				
Defesa de:	Tese de Doutorado, nº 78, PPGODONTO				
Data:	Vinte e Cinco de Julho de Dois Mil e Vinte e Dois	Hora de início:	09:00	Hora de encerramento:	[12:40]
Matrícula do Discente:	11813ODO017				
Nome do Discente:	Andomar Bruno Fernandes Vilela				
Título do Trabalho:	Efeito do tipo de traumatismo e da contenção dental na dentadura mista e permanente - Avaliação biomecânica pelo método de elementos finitos				
Área de concentração:	Clínica Odontológica Integrada				
Linha de pesquisa:	Biomecânica Aplicada à Odontologia				
Projeto de Pesquisa de vinculação:	Biomecânica Aplicada à Odontologia				

Reuniu-se em Web Conferência pela plataforma Zoom, em conformidade com a PORTARIA Nº 36, DE 19 DE MARÇO DE 2020 da COORDENAÇÃO DE APERFEIÇOAMENTO DE PESSOAL DE NÍVEL SUPERIOR - CAPES, pela Universidade Federal de Uberlândia, a Banca Examinadora, designada pelo Colegiado do Programa de Pós-graduação em Odontologia, assim composta: Professores Doutores: Camilla Christian Gomes Moura (UFU); Priscilla Barbosa Ferreira Soares (UFU); Gabriela Campos Mesquita (UniRV); Marília Leão Goettems (UFPel); Carlos José Soares (UFU); orientador(a) do(a) candidato(a).

Iniciando os trabalhos o(a) presidente da mesa, Dr(a). 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 arguição 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 arguir o(a) candidato(a). Ultimada a arguição, que se desenvolveu dentro dos termos regimentais, a Banca, em sessão secreta, atribuiu o resultado final, considerando o(a) candidato(a):

[A]provado(a).

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O competente diploma será expedido após cumprimento dos demais requisitos, conforme as normas do Programa, a legislação pertinente e a regulamentação interna da UFU.

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Documento assinado eletronicamente por **Camilla Christian Gomes Moura**, **Professor(a) do Magistério Superior**, em 25/07/2022, às 12:56, conforme horário oficial de Brasília, com fundamento no art. 6º, § 1º, do Decreto nº 8.539, de 8 de outubro de 2015.

Documento assinado eletronicamente por **Gabriela Campos Mesquita**, **Usuário Externo**, em 25/07/2022, às 17:25, conforme horário oficial de Brasília, com fundamento no art. 6º, § 1º, do Decreto nº 8.539, de 8 de outubro de 2015.

Documento assinado eletronicamente por **Marilia Leão Goettems**, **Usuário Externo**, em 26/07/2022, às 09:36, conforme horário oficial de Brasília, com fundamento no art. 6º, § 1º, do Decreto nº 8.539, de 8 de outubro de 2015.

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Referência: Processo nº 23117.052524/2022-98 SEI nº 3784414

Dados Internacionais de Catalogação na Publicação (CIP)
Sistema de Bibliotecas da UFU, MG, Brasil.

V699e
2021

Vilela, Andomar Bruno Fernandes, 1991-
Efeito do tipo de traumatismo e da contenção dental na dentadura mista e permanente [recurso eletrônico] :avaliação biomecânica pelo método de elementos finitos / Andomar Bruno Fernandes Vilela. - 2021.

Orientador: Carlos JoséSoares.
Coorientador: AntheunisVersluis.
Tese (Doutorado) - Universidade Federal de Uberlândia, Programa de Pós-Graduação em Odontologia.
Disponível em: http://doi.org/10.14393/ufu.te.2022.5026
Inclui bibliografia.

1. Odontologia. I. Soares, Carlos José, 1965-, (Orient.). II. Versluis, Antheunis, 1964-, (Coorient.). III. Universidade Federalde Uberlândia. Programa de Pós-Graduação em Odontologia. IV. Título.

CDU: 616.314

André Carlos Francisco
Bibliotecário – CRB-6/3408

DEDICATÓRIA

Dedico primeiramente à **Deus**, que me proporcionou um dos períodos mais valiosos de minha vida que foram os anos de Mestrado e Doutorado. Deus me transformou, me fez passar por experiências fantásticas e me propiciou conhecer pessoas maravilhosas e que levarei para sempre. Se eu pude chegar até aqui e realizar vários sonhos, foi porque ele esteve sempre ao meu lado.

Dedico esta tese à minha querida **mãe**, que sempre batalhou para que os filhos tivessem do que comer. Minha mãe que sempre esteve ao meu lado e abdicou de tanto para cuidar dos seus filhos. Sem você esse momento não existiria. Eu amo você!

À **Thalita**, minha esposa, que há oito anos sempre me apoiou nas minhas escolhas, sempre me incentivou a estudar, a fazer mestrado, doutorado e doutorado sanduíche. Você nunca, em momento algum, se opôs aos estudos, mesmo em momentos de renúncia e dificuldade financeira ou mesmo quando ficamos 1 ano afastados. Você sempre me dizia para aceitar as oportunidades. Você é um exemplo de dedicação, esforço e força de vontade e, assim sendo, sempre me exigiu o mesmo. Você me estimula a ser melhor, a estudar mais, a me dedicar mais e não à toa, cheguei até aqui, pois tive você ao meu lado.

Dedico também ao meu mestre, mentor e orientador, **Prof. Carlos José Soares**. Em alguns momentos da minha vida eu vejo o tanto que Deus sempre está ao meu lado. Quando Deus me oportunizou estudar com você, eu pude ver o quanto ele me abençoou. Eu não poderia ter outro orientador, você é o espelho do que eu gostaria de ser e, se um dia eu tiver a chance de ser um professor, gostaria de ser como você. Você, além de professor é amigo, conselheiro, orientador, um mestre e em muitos momentos um pai. Você me ensinou muito, me fez crescer e amadurecer. Professor Carlos, você é uma pessoa correta, justa, que trabalha arduamente para a Odontologia, para a Ciência e para que seus alunos cresçam. Você nunca disse "não" quando um aluno te pediu uma oportunidade! Nunca! E eu gostaria de ser assim. Você me oportunizou experiências que eu nunca havia imaginado que poderia ter. Desde a primeira vez que você me confiou a escrita de um resumo para o GBMD 2016, resultando na minha primeira apresentação de um trabalho, até a oportunidade de poder conhecer outros países, estudar em uma universidade no exterior. Seu amor pelo trabalho, pela UFU, FOUFU e pelo PPGO me mostram a importância de gostarmos daquilo que fazemos. Foram 6 anos de tantos outros momentos que nunca esquecerei. Pude conhecer pessoas de todo o mundo, vivenciar diferentes culturas, aprender sobre diversos temas dentro e fora da odontologia. Pude ministrar aulas, melhorar como profissional clínico e como professor. Mudei, amadureci e tudo isso graças a um dia em que te pedi uma oportunidade e você prontamente quis me ajudar. Sou muito grato! Muito! Você me conhece e sabe que serei eternamente grato. Sou e serei sempre, com muito orgulho, aluno do Professor Carlos José Soares.

AGRADECIMENTOS

To **Antheunis Versluis e Daranee Versluis**. Thank you guys for everything during the 2019-2020 year that I studied with both of you. You guys gave me the opportunity to fulfill a dream. This thesis has a lot of your hard work in it and I'm pretty sure that without your effort, this thesis would not be accomplished. You guys are amazing! Thanks for the opportunity and for always have taken care of me. I'll always have the memories from Memphis with me. I hope to keep working with you and I also hope to visit you guys again and have another lunch together. See you guys soon!

À **Professora Priscilla Soares**, a quem eu sou muito grato e que sempre foi muito presente na minha formação durante o Mestrado e o Doutorado. Você sempre foi uma pessoa fantástica comigo e me adotou desde o início do meu Mestrado, em 2016, me propondo várias oportunidades. Me recordo até hoje da primeira oportunidade que tive em participar de um artigo científico. Foi após seu convite que pude, pela primeira vez, ter a experiência em escrever, participar e publicar um trabalho científico. Pude também, pela primeira vez, realizar um sonho de visitar outro país acompanhando você e o Prof. Carlos em um congresso. Obrigado por ter você ter me dado tantas oportunidades, você não foi minha orientadora e, ainda assim, se preocupou comigo, e por isso, eu sempre te considerei a minha coorientadora. Você é um exemplo de liderança, de pesquisadora brasileira e, assim como o Prof. Carlos, é um exemplo de quem trabalha incansavelmente. Você faz muito mais do que é preciso e, não à toa, você é fundamental para a nossa pós-graduação hoje. Muito obrigado.

À **Professora Gabriela Mesquita** que sempre, mesmo em momentos de dificuldade, foi exemplo de dedicação e trabalho duro. Você sempre trouxe aos seus colegas e amigos de pós-graduação a sua alegria e carinho. Hoje te acompanho e vejo, via redes sociais, as diversas homenagens que você recebe de seus alunos. Não é por menos, sua vontade e insistência em sempre ajudar o próximo claramente resultaria em uma excelente professora que daria o melhor para os seus alunos. Nunca me esqueço de você na Clínica de Trauma preocupada se os pacientes precisavam de água, se estavam confortáveis nas

cadeiras. Preocupava-se com os alunos e fazia amizade por todos os cantos. Obrigado por tudo.

À **Professora Camilla**. Professora, guardo com muito carinho a viagem que pude realizar acompanhando você, a Profa. Priscilla e o Prof. Carlos para o IADR. Me recordo muito bem das conversas fora do ambiente acadêmico e, nesses momentos, pude entender um pouco mais da sua história, recebi conselhos e pude entender o porquê você é tão querida pelos seus alunos. Após aquela viagem, percebi o quanto você é humana e afetuosa. Quisera eu ter mais oportunidades de trabalhar com você. Quero confessar que em alguns momentos li algumas de suas publicações e só consigo pensar o quanto você é inteligente para delinear pesquisas e ter ideias fora da curva. Acho que assim como o Prof. Carlos, a Profa. Priscilla, você é um dos pilares da nossa pós-graduação e fico muito contente de você participar desse momento tão importante em minha vida. Obrigado.

À **Professora Marília**, que mesmo sem saber, participou em vários momentos da minha trajetória na pós-graduação. Professora, li vários de seus trabalhos e a senhora sempre foi um nome recorrente nas minhas pesquisas no PubMed. De forma indireta os seus trabalhos me ajudaram na escrita da minha dissertação de mestrado. Acho que cada um de nós temos nossos pesquisadores que gostaríamos de conhecer e a senhora era uma dessas pessoas. Agradeço imensamente em poder participar desse momento tão importante em minha vida. Muito obrigado.

À **Professora Fabiana Sodré** que muito contribuiu em momentos chaves da minha trajetória acadêmica. A senhora contribuiu muito para um melhor direcionamento dos artigos resultantes do meu mestrado durante o processo de qualificação. No início do meu doutorado, na fase de delineamento de projeto, as suas considerações foram fundamentais para que eu chegasse até aqui. O meu muito obrigado.

À **professora Renata** que, por muito tempo, foi uma colega de pós-graduação que sempre transmitiu muita tranquilidade, segurança, perspicácia, conhecimento e raciocínio rápido. Você sempre foi muito determinada e tem uma grande capacidade de liderança que eu via ecoar na Clínica de Hebiatria não só pelo pleno funcionamento das atividades, como também pelo respeito que os alunos tinham por você. Já presenciei você ajudando colegas da pós-graduação com diferentes metodologias, análises estatísticas e cálculo amostral e me incluo nesse grupo de pessoas que foram ajudadas. Você entende como poucas a respeito de saúde pública e hoje eu vejo que eu poderia ter aprendido muito mais com você, pois é algo que vejo refletido no meu dia-a-dia. Muito obrigado.

Ao **professor Flávio**, a quem eu tenho grande admiração como clínico e como professor. As suas disciplinas na pós-graduação me marcaram muito e as considero fundamentais na minha trajetória. As discussões de caso realizadas em suas disciplinas ainda repercutem durante as minhas tomadas de decisão na clínica. Sou também muito mais criterioso a analítico quando leio algum artigo científico e quando realizo anamnese e diagnóstico clínico em meus pacientes. Obrigado.

Aos **professores da FOUFU**, **Guilherme Almeida, Luiz Paranhos, Veridiana, Paulo César, Guilherme Pimentel, e demais professores** que tanto me ensinaram durante as disciplinas do mestrado e doutorado.

Aos meus queridos amigos que fiz durante meu período de Mestrado e Doutorado: **Gabriel, Laís, Stella, Monise, Erick, Lilian, Juliana e Luciana**. Vocês me ensinaram muito e fizeram parte dessa jornada. Sinto muita saudade daqueles que já terminaram seu período na UFU. A vida se encarregará de dar diferentes caminhos a cada um, porém os levarei comigo sempre.

Ao grupo de pesquisa **BIAOR**. Aprendi muito com esse grupo e pude conviver com pessoas muito mais inteligentes que eu e isso resultou em um período de muito aprendizado.

À **University of Tennessee** – Health Science Center, onde pude realizar parte da minha tese.

Ao **CPBIO**, minha segunda casa, onde pude realizar toda minha pesquisa de mestrado e agora pude realizar grande parte de toda a minha tese.

Agradeço à **UFU, FOUFU, ao PPGO** por todas as oportunidades. Fui e sou muito feliz aqui.

À **CAPES** pela indispensável bolsa de estudos nacional e internacional.

À **Fapemig e CNPq** que financiaram de instrumentos, materiais e equipamentos que me ajudaram em minha pesquisa e irão ajudar vários outros alunos.

EPÍGRAFE

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

Conan O'Brien

Sumário

LISTA DE ABREVIATURAS E SIGLAS

% - Porcentagem

et al. – E colaboradores

mm – Unidade de comprimento (milímetro)

MPa – Força/área (Mega Paschoal)

N – Unidade de pressão – carga aplicada (Newton)

3D – Tridimensional

S – Unidade de tempo (segundo)

DICOM – Digital Imaging and Communication in Medicine

STL – Stereo Lithography

UFU – Universidade Federal de Uberlândia

FOUFU – Faculdade de Odontologia da Universidade Federal de Uberlândia

RESUMO

RESUMO

O traumatismo dentoalveolar constitui problema de saúde pública devido a sua elevada frequência, por envolver pacientes jovens, pelos custos e complexidade do tratamento e ainda pela necessidade de acompanhamento por longos períodos. Quando ocorre algum tipo de traumatismo severo como a avulsão, o reposicionamento e contenção dental se fazem necessários. A rigidez, estabilidade e extensão das contenções nas diferentes faixas etárias gera extrema diversidade de protocolos. Porém, ainda se evidencia carência de informações quanto ao comportamento biomecânico das contenções após evento de traumatismo dentoalveolar em pacientes na fase de dentição mista e dentadura permanente. Além disso, o procedimento de remoção destas contenções ainda pode ser considerado empírico pelo cirurgião-dentista, sem, no entanto, se basear em evidência científica. Esta tese se estrutura em três objetivos específicos: **Objetivo 1:** Avaliar o efeito de diferentes tipos de contenção semirrígida em modelo tridimensional simulando incisivo permanente avulsionado na distribuição de tensões e deformações no dente traumatizado e nas estruturas dentoalveolares adjacentes. **Objetivo 2:** Avaliar o efeito da extensão da contenção em modelos simulando dentadura mista com diferentes estágios de rizólise por meio de modelo de elementos finitos tridimensionais de impacto dinâmico. **Objetivo 3:** Avaliar de forma experimental *in vitro* o efeito preventivo de dano iatrogênico causado ao esmalte na remoção de contenção dental variando a iluminação de luz violeta e o tipo de instrumento rotatório. Estes objetivos são significativamente cruciais para a possível geração e simplificação de protocolos na escolha do tipo contenção ideal e sua remoção para casos de traumatismo dentoalveolar, buscando assim, agregar evidência ao tratamento e manejo destes pacientes.

Palavras-chave: traumatismo dentoalveolar, contenção dental, avulsão, intrusão, tensão, deformação, análise por elementos finitos.

ABSTRACT

ABSTRACT

Traumatic dental injuries (TDI) are a public health problem, due to its high prevalence and recurrence rate, mainly in young patients. TDI's treatment also involves high cost, complex treatment and it needs long-term follow-up. However, there are still a lack of evidence of the biomechanical behavior of splinting after TDI in mixed and permanent dentures and consequences during splinting removal on enamel. In severe dental trauma injuries, it is extremely important the reposition and splinting of the injured tooth, but the stiffness, stability and the extension of the splint on the different ages still induces uncertainty and generates a diversity and non-unified protocols. Besides that, the removal procedures of the dental splints are still based in empirical decisions. This thesis was structure in three specific aims. **First Aim**: Evaluate the effect of different types of semi-rigid splint in patient specific three-dimensional model, generated from a cone-beam tomography, simulating a permanent avulsed incisor on strain and stress distribution on traumatized tooth and at adjacent teeth and dentoalveolar structures. **Second Aim**: To evaluate the effect on mobility of splint materials and extensions for an avulsed central incisor, stabilized with and without the adjacent incisor under intrusive and extrusive loading under different periodontal ligament (PDL) conditions. **Third Aim**: To evaluate in an experimental in vitro the preventive effect of iatrogenic damage caused to the enamel in the removal of dental containment varying the violet light illumination and the type of rotating instrument. These objectives are significantly crucial for the possible generation and simplification of protocols in the choice and removal of the splint for dental trauma cases, in order to facilitate the treatment and clinical management of these patients.

Keywords: dental trauma, dental splint, avulsion, stress, finite element analysis.

INTRODUÇÃO E REFERENCIAL TEÓRICO

1. INTRODUÇÃO E REFERENCIAL TEÓRICO

O declínio nos índices de cáries, verificados em estudos epidemiológicos em países em desenvolvimento, e o consolidado conhecimento na sua prevenção e tratamento (Frazão, 2012), promove e acentua o traumatismo dentoalveolar como um dos principais fatores de consultas odontológicas pediátricas (Mendoza-Mendoza *et al*., 2015). O traumatismo dentoalveolar já é considerado a quinta doença/lesão mais prevalente no mundo após cáries, cefaléia anemia e perda auditiva (Petti *et al*., 2018a). Além disso, tratamento dessas lesões é considerado mais oneroso e demorado quando comparado a todas as outras lesões corporais, portanto, a reabilitação em pacientes mais carentes é menos provável de ocorrer (Borum & Andreasen, 2001). Isso leva a problemas sociais, emocionais, fonéticos e funcionais, principalmente e crianças e adolescentes (Freire-Maia *et al.,* 2015; Borges *et al.,* 2017). Esta alta prevalência do traumatismo dentoalveolar é evidenciada por mais de um bilhão de casos em todo o mundo (Petti *et al*., 2018b), envolvendo com maior prevalência pacientes jovens, caracterizando-se assim, como importante problema de saúde pública (Mendoza-Mendoza *et al*., 2015).

No entanto, o traumatismo dentoalveolar ainda é negligenciado pelas organizações de saúde pública e, muitas dessas lesões, não são nem sequer classificadas de acordo com o último material informativo “Classificação Internacional de Doenças (CID-11)” da Organização Mundial da Saúde. Isso repercute em consequências importantes, como a falta de conscientização das autoridades de saúde pública, a confusão de diagnóstico pelo cirurgião-dentista, a classificação incorreta ou não-classificação das lesões, com posterior manejo inadequado do paciente. Tudo isso leva ao aumento das disparidades no estado de saúde bucal entre crianças e adolescentes privilegiados e desprivilegiados, com consequentes diferenças no bem-estar social, emocional e psicológico (Petti *et al*., 2018a).

As fraturas de esmalte e dentina e a extrusão estão entre as lesões mais comuns na dentadura permanente (Hecova *et al*., 2010). No entanto, quando o trauma provoca danos aos tecidos periodontais, ligamento periodontal e osso alveolar, como em casos da extrusão, avulsão, intrusão e luxação lateral, ou fraturas complexas (fraturas radiculares), há necessidade de estabilização com o uso de contenções dentais, rígidas ou semi-rígidas (Bourguignon *et al.,* 2020). Estas contenções são temporárias, variando o período em função do tipo e extensão do trauma dental (Kahler *et al*., 2016).

Dentre todas as lesões dentárias ou periodontais, a avulsão é uma das lesões mais complexas, e nestes casos, as complicações decorrentes do traumatismo dentoalveolar podem ser imediatas ou tardias, ou seja, podem ocorrer dentro de semanas, meses ou até mesmo depois de anos (Hecova *et al*., 2010). A anquilose é uma das complicações mais comuns em lesões de avulsão dental e está relacionada ao manejo do dente, tempo que este se manteve fora do alvéolo, assim como à armazenagem inadequada do elemento dental (Fuss *et al*., 2003). O tipo de contenção dental também está relacionado com o prognóstico dentoalveolar, sendo que, a necrose pulpar e reabsorções radiculares são mais comuns em casos de avulsão quando utilizadas contenções rígidas (Kahler & Heithersay, 2008). As contenções dentais são fundamentais para a regeneração tecidual do periodonto que foi danificado pelo traumatismo dento-alveolar, e fazem parte de um tratamento integrado (Oikarinen, 1990). Sejam rígidas ou semi-rígidas, as contenções devem facilitar o reposicionamento de dentes deslocados de sua posição original, devem prevenir a ingestão ou inalação acidental dos dentes traumatizados, e também possuem o objetivo de proteger o dente contra forças traumáticas durante a fase de regeneração dos tecidos periodontais (Berthold *et al*., 2009; Berthold *et al*., 2010).

A rigidez das contenções varia dependendo do tipo de trauma dental, em casos onde ocorreram injúrias ao ligamento periodontal, devido ao deslocamento do dente em seu alvéolo, são indicadas contenções semirrígidas, também denominadas de contenções flexíveis, estas permitem a transmissão de forças funcionais durante a mastigação (Bourguignon *et al.,* 2020; Fouad *et al.,* 2020). Quando o traumatismo dentoalveolar provoca danos consideráveis à estrutura óssea, ocasionando fratura do processo alveolar, o guia da Associação Internacional do Trauma Dental (IADT), endossado pela Academia Americana de Odontopediatria, ainda não é claro à qual o tipo de contenção deve ser utilizada (Bourguignon *et al.,* 2020). Por outro lado, o guia da Associação Americana de Endodontia indica o uso de contenção semirrígida para qualquer lesão que cause danos periodontais, inclusive para casos onde ocorra fratura alveolar (AAE, 2013). Os estudos geralmente indicam que o prognóstico das lesões de fratura de tábua óssea é determinado pela lesão e não por fatores associados à contenção, seja a contenção rígida ou a flexível (Kahler & Heithersay, 2008; Lauridsen *et al*., 2016).

A variabilidade de materiais, utilizados na realização de contenções dentais, descritos na literatura, assim como, a dificuldade na definição e conceituação do que é considerada contenção semirrígida ou rígida, leva a abordagem quase empírica na tomada de decisão clínica, criando assim possíveis complicações no tratamento em casos de lesão grave. Além do mais, a ausência de estudos biomecânicos acerca deste tópico é indicativa de que este tema precisa ser melhor abordado, buscando assim, melhores evidencias que amplie o prognóstico terapêutico e até mesmo oportunizando alternativas mais viáveis e acessíveis para o cirurgião-dentista.

O uso de contenções dental em pacientes com na dentadura permanente é conhecido por ser importante para o processo de reparo periodontal do paciente (Bourguignon *et al.,* 2020). Porém, a prevalência do traumatismo dentoalveolar em pacientes na fase de dentadura decídua ou mista é consideravelmente alta (Mendoza-Mendoza *et al*., 2015) e correspondem a cerca de 18% das lesões somáticas (Glendor *et al*., 1996; Glendor & Andersson, 2007). Assim, fatores relacionados à contenção como a extensão, o tipo de material e quais dentes devem ser envolvidos em caso de reabsorção fisiológica dos decíduos ainda é escasso de informações (Day *et al*., 2020). Outro fator importante em lesões na dentadura mista é a magnitude das lesões em dentes com ápice aberto e o possível comprometimento dos dentes adjacentes ainda em desenvolvimento (Vilela *et al.,* 2019a). Sabe-se que o trauma em dentes com ápice aberto pode gerar complicações como anquilose (Tsiligaridis *et al*., 2012), porém, ao conhecimento dos autores, ainda não existem estudos sobre os possíveis efeitos que o traumatismo dentoalveolar severo na dentadura mista, podem causar sobre as estruturas dentoalveolares adjacentes frente a diferentes forma de contenção.

Recentes e significativos avanços foram obtidos pelo grupo de pesquisa, em estudos acerca do traumatismo dentoalveolar, utilizando-se da metodologia de elementos finitos (MEF). Análises bidimensionais de impacto associadas ao uso do protetor bucal foram inicialmente descritas em 2015 (Veríssimo *et al*., 2015). Este estudo foi o primeiro, utilizando-se desta metodologia, que buscou evidenciar a importância do uso de protetores bucais customizados para diminuir a probabilidade de traumatismo dentoalveolar. Porém, novos estudos buscaram elucidar outros questionamentos clínicos, atrelando métodos experimentais laboratoriais com o MEF, para validação dos resultados (Veríssimo *et al*., 2016a). Além disso, ainda com análises bidimensionais, buscou-se evidenciar a espessura ideal deste protetor customizado (Veríssimo *et al*., 2016b) e o efeito dos dentes antagonistas na biomecânica do trauma (Veríssimo *et al*., 2017). Mais recentemente, novos estudos envolvendo modelos 2D buscaram responder novos questionamentos, com à associação do protetor bucal em pacientes reabilitados com implantes (Carvalho *et al*., 2018) e o traumatismo dentoalveolar em crianças na fase de dentadura decídua (Vilela *et al*., 2019b). Ainda seguindo esta evolução, o grupo conseguiu avançar neste tipo de análise ao construir modelo tridimensional, com o objetivo de explicar o efeito do trauma em dente permanente sobre os dentes adjacentes (Vilela *et al*., 2019a). No entanto, com a contínua necessidade de resolução de novos questionamentos clínicos relevantes, é importante a consideração de novos passos e necessidade de aprofundar em análises mais complexas do MEF que possam solucionar e responder de forma mais consistente problemas cotidianos como o traumatismo dentoalveolar. Portanto, se faz necessário e fundamental a interação com núcleos internacionais de alta competência na geração de modelos e de novas análises.

Para o desenvolvimento destas metodologias, o uso do MEF é uma maneira oportuna para responder alguns destes questionamentos clínicos. O MEF é um método matemático que calcular por meio de modelos computacionais, deslocamentos, tensões e deformações em condições complexas. 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 em situações nas quais as metodologias tradicionais não conseguem explicar os fenômenos ocorridos, o MEF pode auxiliar a solução destes desafios. 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).

PROPOSIÇÃO

Proposição

Objetivo Geral

Avaliar os efeitos dos tipos de contenções dentais e o dano iatrogênico causado ao esmalte na remoção de contenção dental sobre as estruturas dentárias e periodontais. Com isso, objetiva-se alcançar melhor protocolo visando o aumento da segurança para a execução desses procedimentos clínicos, com maior previsibilidade e menor dano.

Objetivos específicos

Objetivo específico 1 - Capítulo 1: Splint stiffness and extension effect on avulsion simulation of permanent incisor – a patient-specific finite element analysis

Avaliar por meio de análise computacional pelo método de elementos finitos tridimensional de dentadura permanente, a mobilidade e distribuição de tensões em incisivo central superior avulsionado estabilizado com três tipos de contenções dentais e com diferentes extensões sob cargas mastigatórias fisiológicas.

Objetivo específico 2 - Capítulo 2: Dental trauma splints for mixed dentition – A finite element analysis evaluation of splint material, splint extension, missing teeth, and PDL representation

Avaliar, utilizando o método de elementos finitos, o deslocamento de incisivo central avulsionado na dentição mista, com e sem incisivo central adjacente, estabilizado com diferentes extensões de contenções flexíveis e rígidas frente a diferentes tipos de simulação de ligamento periodontal.

Objetivo específico 3 - Capítulo 3: Evaluation of Fluorescence-aided Identification Technique (FIT) with different lighting sources and rotatory instruments for dental trauma splint removal

Investigar, por meio de estudo *in vitro*, o efeito da iluminação adicional, com presença de luz violeta em LED com multiespectro de comprimento onda ou do uso de lanternas intraorais de baixo custo, associado ao uso de ponta diamantada ou broca multilaminada em baixa velocidade na preservação de danos iatrogênicos ao esmalte na remoção da contenção dental.

CAPÍTULO 1

1.1 - Capítulo 1

Artigo publicado no periódico Dental Traumatology

Splint stiffness and extension effects on a simulated avulsed permanent incisor-A patient-specific finite element analysis

Andomar Bruno Fernandes Vilela, Priscilla Barbosa Ferreira Soares, Thiago Leite Beaini, Antheunis Versluis, Carlos José Soares

DOI: 10.1111/edt.12705

Received: 2 March 2021 | Revised: 23 June 2021 | Accepted: 24 June 2021

DOI: 10.1111/edt.12705

ORIGINAL ARTICLE

Dental Traumatology WILEY

Splint stiffness and extension effects on a simulated avulsed permanent incisor—A patient-specific finite element analysis

Andomar Bruno Fernandes Vilela[1] | Priscilla Barbosa Ferreira Soares[2] | Thiago Leite Beaini[3] | Antheunis Versluis[4] | Carlos José Soares[1]

[1]Department of Operative Dentistry and Dental Materials, Dental School, Federal University of Uberlândia, Uberlândia, Brazil

[2]Department of Periodontology and Implantology, Dental School, Federal University of Uberlândia, Uberlândia, Brazil

[3]Department of Preventive and Social Dentistry, Federal University of Uberlândia, Uberlândia, Brazil

[4]Department of Bioscience Research, College of Dentistry, University of Tennessee Health Science Center, Memphis, TN, USA

Correspondence
Carlos José Soares, Department of Operative Dentistry and Dental Materials, Dental School, Federal University of Uberlândia, Avenida Pará, 1720, Bloco 4L, anexo A, sala 42, Campos Umuarama, Uberlândia, Zip-Code: 38400-902, Minas Gerais, Brazil.
Email: carlosjsoares@ufu.br

Funding information
PrInt-CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior); CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico); FAPEMIG (Fundação de Amparo à Pesquisa de Minas Gerais)

Abstract

Background/Aim: Splinting is an important procedure after avulsion. However, the role of splint stiffness and extension is not fully understood. The aim of this study was to evaluate the effect of splint stiffness and extensions on the mobility and stress on an injured tooth under physiological biting load.

Materials and methods: Three-dimensional (3D) finite element models were created from a cone beam computer tomogram of a patient with normal occlusion. An avulsion injury of the right central incisor was created with a 1000 N load application on the palatal of the injured tooth, causing increased socket width. Splints made from four materials were tested: 0.9 mm diameter wire-composite splint (WCS1), 0.4 mm diameter wire-composite splint (WCS2), 1.0 mm diameter nylon-composite splint (NCS), and a 2 mm high by 0.2 mm thick plastic strip composite splint (PSS). Three splint extensions (involving 6, 5, and 3 teeth) were evaluated. Mobility of the avulsed tooth and the maximum principal stress distributions in the adjacent teeth were calculated.

Results: The injured incisor tooth mobility was not affected by the splint extensions. The NCS and PSS stabilized the avulsed incisor but allowed, respectively, 10 and 20 times more mobility under horizontal loading than the WCS1, which inhibited most mobility, while the WCS2 allowed double the mobility compared with WCS1. The NCS and PSS allowed more tooth mobility, mainly in the extrusion direction. Splints were 2–3 times more effective in limiting mobility under intrusive loads than extrusive loads. High levels of stress were found at the base of the composite attachments in the adjacent incisors.

Conclusion: Splinting an avulsed tooth to one or two teeth bilaterally using a nylon splint or a plastic strip is appropriate for tooth stabilization and should be recommended over the 0.4mm wire-composite splint, while the 0.9 mm orthodontic wire is too rigid and not recommended.

KEYWORDS
dental trauma, displacement, nylon splint, tooth mobility, wire-composite splint

1 | INTRODUCTION

Tooth avulsion is one of the most critical dental injuries where a tooth is completely displaced from its socket.[1] This injury requires emergency consultation to perform tooth replantation as the first aid procedure,[2] to determine the tooth's prognosis and to prevent harmful sequalae.[3] One of the main procedures during an initial consultation after tooth replantation is splinting, which helps to keep a dislodged tooth in its correct position, preventing accidental ingestion or inhalation, and protecting the tooth against harmful chewing forces.[4] However, an incorrect approach during the splinting procedure, such as the inadequate choice of splinting material rigidity (stiffness), might lead to tooth ankylosis.[5]

The International Association of Dental Traumatology (IADT) guidelines suggest the use of flexible splints to treat avulsion injuries, allowing physiological movement of the avulsed tooth.[6] Many *in vitro*[7–9] and *in vivo* studies[10,11] have measured tooth mobility generated by different dental splint materials to determine their flexibility. However, it may not be as simple to discern rigid and flexible materials, since a large number of patients with avulsion injuries have been treated with rigid splints.[12,13]

Splint extension is also not fully understood, since different lengths have been reported and the guidelines are not clear. While some studies recommend splinting the avulsed tooth to only one uninjured tooth,[7–9] other studies recommend splinting the injured tooth to two adjacent teeth.[4,14] Other studies[15,16] and case reports[17–19] have recommended using the whole anterior segment, involving the six anterior teeth.

Avulsion injury simulations in *in vitro* studies are usually performed with soft materials to simulate the periodontal ligament (PDL),[11,15] since testing the biomechanical behavior *in vivo* is impractical. However, an avulsion injury may also cause damage to the bone and to the periodontal structures,[20,21] which is not easily replicated. Finite element analysis (FEA) is widely used in such complex situations to create a better understanding of the physiological consequences related to dental trauma scenarios by evaluating stress and deformation.[22,23] This numerical method could also help to evaluate how various splinting options could modify the mobility of an avulsed tooth.

To the best of the authors' knowledge, the effect of splinting materials and splint extensions has not been evaluated using a patient-specific finite element analysis. Therefore, the aim of this study was to evaluate the mobility of a tooth when three types of dental splints with different extensions are used under physiological chewing loads. The null hypotheses tested were: (a) different splint materials would not affect tooth mobility of the avulsed tooth, and (b) the tooth mobility caused by biting loads would not be affected by different splint extensions.

2 | MATERIALS AND METHODS

This study followed the Declaration of Helsinki, respecting the ethical principles for medical research involving human subjects and was approved by the Ethics Committee of the Federal University of Uberlândia with protocol number 1.776.692. The cone beam computed tomography (CBCT) scan used in this study was selected from the image data bank at the Federal University of Uberlândia, and the patient chosen had normal occlusion. The CBCT (i-CAT GXCB-500™ Imaging Sciences International) scan had a voxel size of 0.2 mm and the image data consisted of a total of 432 slices, obtained with 23 sec of acquisition time and exposure parameters of 120 kV and 5.0 mA.

The CBCT was imported into an interactive medical imaging software program (Mimics 18.0, Materialise Dental) to segment the maxillary structures as cortical and trabecular bone, enamel, and dentin. This segmentation was performed by using an image density thresholding tool that isolates different structures by converting grayscale values into binary images (Figure 1A).[24] The periodontal ligaments (PDL) of all six anterior teeth were created by Boolean operations, creating a tissue layer around the roots with 0.25 mm thickness. The aim of this procedure was to create a smooth PDL structure that was not possible from the CT scan with the thresholding tool due to the thin PDL space.

After segmentation of the maxillary structures (Figure 1B), the resulting 3D triangle-based surface masks were exported in stereolithography (STL) format to a pre-processing software program (MSC. Patran® 2010, MSC. Software) (Figure 1C). The maxillary structures were meshed with solid tetrahedral elements, creating a volumetric mesh. The whole maxillary model was then exported to a design optimization software program (3-Matic 13.0, Materialise Dental). Finer mesh distributions were created in the target areas involving the tooth and splint structures (Figure 1D).

The 3D models were then exported to a finite element analysis software program (Marc/Mentat, MSC. Software). To simulate the widening socket and repositioning of the avulsed tooth, a 1000 N nodal load was applied on the palatal surface of the right central incisor (Figure 2A-C). The applied load forced the tooth against the bone, deforming the cortical and trabecular bone around the socket (Figure 2D). The deformation caused around the right central incisor was locked while the load was removed, creating a wider alveolar socket with a PDL space of 0.7 mm thickness (Figure 2E). The resulting element distribution was recreated to obtain a stress-free mesh featuring the avulsion injury deformation that was used for the subsequent splint analyses (Figure 2F).

Four types of splints were designed: (1) wire-composite resin splint (WCS1) made from 0.036" (0.9 mm) orthodontic wire; (2) wire-composite resin splint (WCS2) made from 0.016" (0.4 mm) orthodontic wire; (3) Nylon-resin composite splint (NCS) made from 0.039" (1.0 mm) fishing line (90-pound test); and 4) plastic strip splint (PSS) that was 2 mm high and 0.2 mm thick, cut from a sterile 0.9% sodium chloride solution bottle used for irrigation (Figure 3A,B). Three splint extensions were simulated: Ext1, anterior arch splint involving 6 teeth, right canine to left canine; Ext2, two teeth splinted on both sides of the injured incisor, right canine to left lateral incisor; and Ext3, one tooth splinted on both sides of the avulsed incisor, right lateral incisor to left central incisor (Figure 3C). One additional model without a splint was analyzed representing a non-splinted uninjured right central incisor.

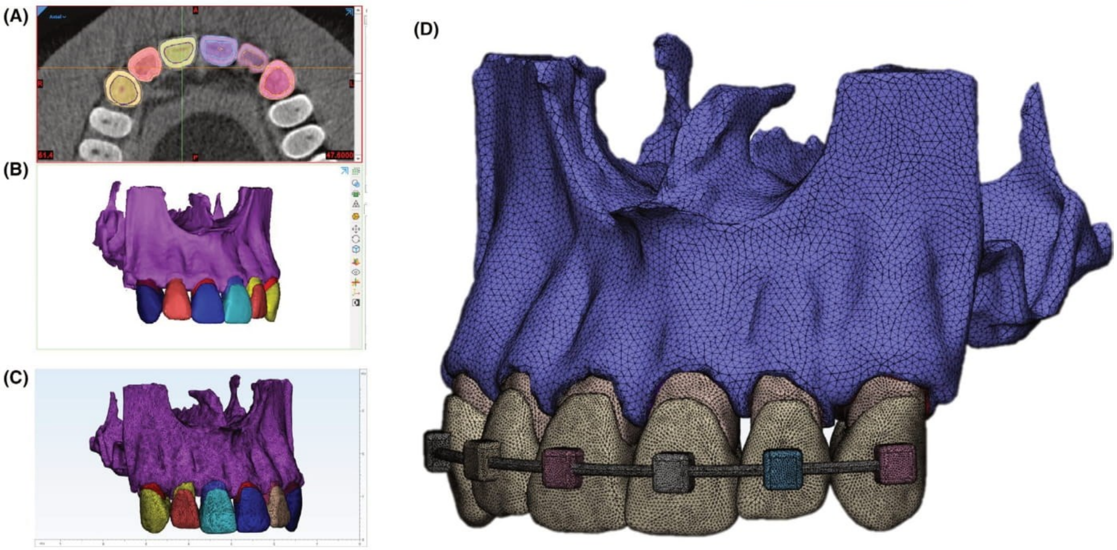

FIGURE 1 3D model generation. (A) Segmentation performed in Mimics 22.0 software for the various maxillary structures using a CBCT image of a patient with permanent teeth; (B) Volumetric structures generated by segmentation; (C) Unorganized surface mesh imported from Mimics in 3-Matic software; (D) 3D model after the remeshing procedure in 3-Matic with fine density mesh on the teeth and the splint

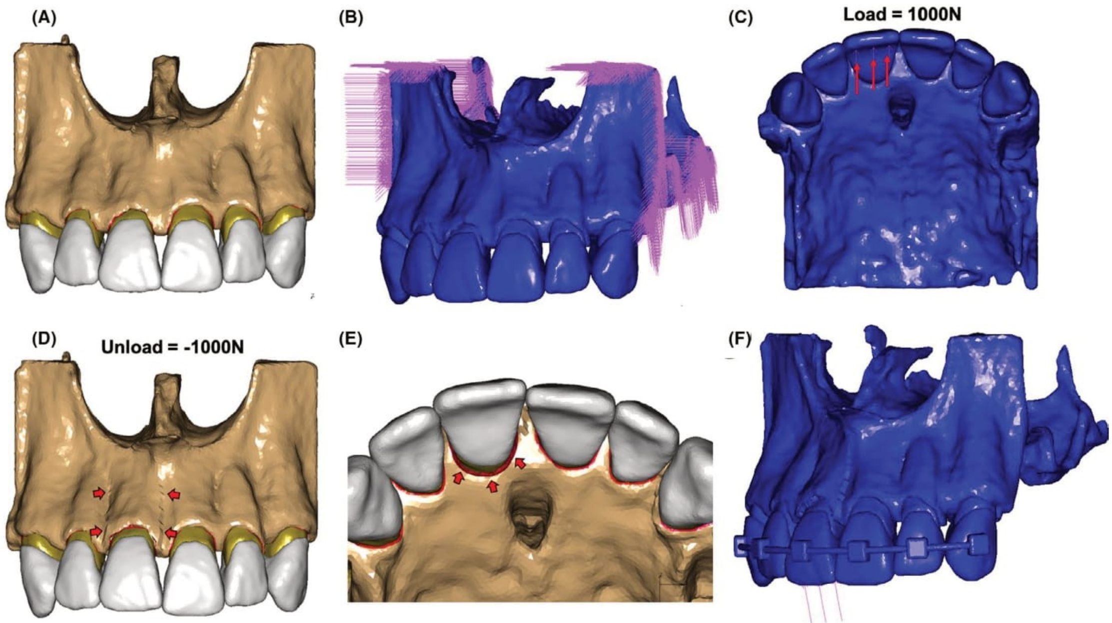

FIGURE 2 Simulation of the upper right central incisor avulsion. (A) 3D Model of the maxilla involving all anterior teeth imported in Marc/Mentat software; (B) Fixed displacements (restraints) applied to the external nodes on the bone cutting surfaces; (C) 1000 N load applied to the palatal surface of the right central incisor to simulate bone deformation during an injurious impact; (D) Cortical and trabecular bone deformation after injury simulation; (E) Palatal view of the misaligned tooth with PDL thickness enlargement after the 1000 N tooth avulsion injury simulation; (F) Splint activation by a biting load application at the palatal side of the avulsed tooth

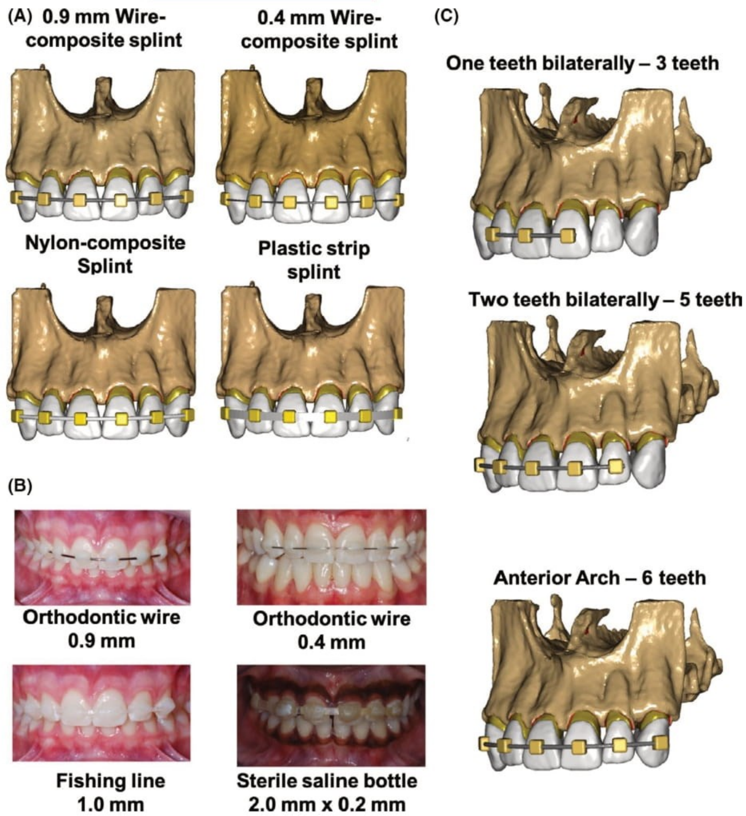

FIGURE 3 Splint materials and designs tested in this study: (A) Avulsed teeth splinted with different materials (WCS1, 0.9 mm wire-composite splint; WCS2, 0.4 mm wire-composite splint; NCS, nylon-composite splint; PSS, plastic strip splint); (B) Clinical examples of the splints tested in this FEA study; (C) three different extensions (Ext 1—anterior arch involving 6 teeth; Ext 2—two adjacent teeth on each side; Ext 3—one adjacent tooth on each side)

TABLE 1 Material properties applied in the 3D models

Structure	Elastic modulus (MPa)	Poisson's ratio	References
Enamel	84,100	0.30	25
Dentin	18,300	0.30	25
Periodontal ligament	50	0.45	26
Trabecular bone	1,400	0.31	27
Cortical bone	13,700	0.33	27
Nylon (Polyamide)	2,700	0.42	28
Saline solution strip	2,550	0.30	28
Orthodontic wire	200,000	0.30	29
Resin composite	18,500	0.24	30

The splints were designed by selecting points perpendicular to the center of the labial surface of each tooth, creating a curve that was then converted into a cylindrical arc or a ribbon. This cylindrical arc was expanded to create the orthodontic wire (WCS) or nylon fishing line (NCS). The ribbon was expanded to create the plastic strip (PSS). The splints were attached to the labial surfaces of the anterior teeth with resin composite. The resin composite was shaped as 3-mm square blocks with rounded edges (Figure 3). A Boolean subtraction procedure incorporated the splints into the resin composite blocks without overlapping or inside-out elements. The contacts between the composite resin, enamel, and the splint were considered as bonded (glued) contacts at the interfaces.

All materials were considered linear-elastic, isotropic, and homogeneous. The applied material properties (elastic modulus and Poisson's ratio) were obtained from the literature (Table 1).[25–30] The PDL around the avulsed tooth was deactivated to simulate a blood clot without attachment, allowing compressive pressure between the root and the bone socket, but not tension.

The maxillary bone was fixed in the X, Y, and Z directions at the external nodes of the cortical bone cutting surfaces. The NCS, WCS, and PSS splints with different extensions were activated with a 1 N biting load on the palatal surface of the avulsed incisor. Horizontal (perpendicular to the tooth axis) and vertical (parallel to the tooth axis) loads were simulated. Both intrusive and extrusive vertical loads were tested. The horizontal load was distributed in three nodes, from the mesial to the distal side of the tooth, representing antagonist contact, while the vertical load was distributed in three nodes on the incisal edge of the injured incisor, resulting in 0.333 N per node.

The mobility of the tooth was defined as the mean displacement of the three loaded nodes. A correction was applied for potential socket displacement, which can occur due to deformation of the maxilla structure. Socket displacement was determined in its notional "center-of-resistance" that was calculated along the longitudinal socket axis, and located at two-thirds the length from the socket apex to the height of the enamel-cementum junction. Stresses (maximum principal stress) generated by the 1 N biting loads were evaluated in the adjacent teeth as an indication for how much the splinted teeth were involved in carrying loads from the avulsed incisor.

3 | RESULTS

The horizontal tooth mobility of the avulsed tooth for each type of splint is shown in Figure 4A. The splint extensions showed similar behavior when horizontal loading was applied, irrespective of the splint type. The WCS1 splint had 96% less mobility compared with the PSS splint and 92% less mobility compared with the NCS splint, while the NCS splint had 53% less mobility than the PSS splint. The WCS2 had 91% and 82% less mobility than the PSS and NCS splints, respectively.

The tooth mobility calculated during simulation of intrusive and extrusive loads is shown in Figure 4B. The different splint extensions had no effect on the splint behavior. Under vertical extrusive loading, the NCS resulted in slightly lower mobility of the avulsed tooth than the PSS splint (23% lower), while the WCS1 and WCS2 resulted in 89% and 84% less mobility, respectively. Under intrusive load, the NCS mobility was slightly higher (5% higher) than with PSS for Ext1 and Ext2, while for Ext2, they had similar values. The mobility with the WCS1 and WCS2 during extrusive loading was 72% and 56% less than the NCS splint. Table 2 lists the tooth mobility values for all simulated conditions, demonstrating that the 1.0 mm NCS splint had mobility values similar to the intact tooth. The PSS splint had higher tooth mobility than the avulsed teeth that had an NCS splint and it was also higher than the intact tooth.

Figure 5 shows the maximum principal stress distribution using a linear color scale, with blue indicating low stress values and yellow being high values. Decreasing the extension of the splints slightly increased the stresses on the adjacent teeth during a biting load. The avulsed incisor splinted with the flexible materials (PSS and NCS) transferred more stress to the two adjacent teeth (right lateral incisor and left central incisor) than the stiffer splinting material (WCS1 and WCS2), whereas teeth splinted beyond these two immediately adjacent teeth had minimal stresses.

4 | DISCUSSION

The null hypotheses were partly rejected. The splint materials affected the mobility of the replanted avulsed incisor. However, splint extensions had no effect on the replanted tooth's mobility. The most flexible nylon–resin composite (NCS) and the plastic strip (PSS) splints, due to their low elastic modulus and small cross sections, reduced mobility of the injured tooth, but maintained some physiological movement which is needed for PDL repair.[10] Compared to the nylon–resin and plastic strip splints, the orthodontic wires (WCS1 and WCS2), with a much higher elastic modulus, resulted in a much stiffer (more rigid) splint, although the WCS2 allowed more mobility of the injured tooth.

The plastic strip used in this study was made from a bottle of a sterile sodium chloride, following recommendations of the 2020 IADT guidelines, that suggested new studies of splint types and lengths as a future area of research.[6] This splint material was chosen because it is commonly available in dental offices. Sodium chloride is indicated to clean the root and socket of an avulsed tooth during the emergency consultation. Splints shaped from bottle strips are therefore low cost. In addition, the shape of the bottle offers the arched curvature, and it is esthetic and convenient because it can be easily attached across different spans of teeth. The 0.2 mm thickness of the PSS material is an important factor in its suitability because splints shaped from thicker-walled bottles will lose much of their flexibility. The fishing line

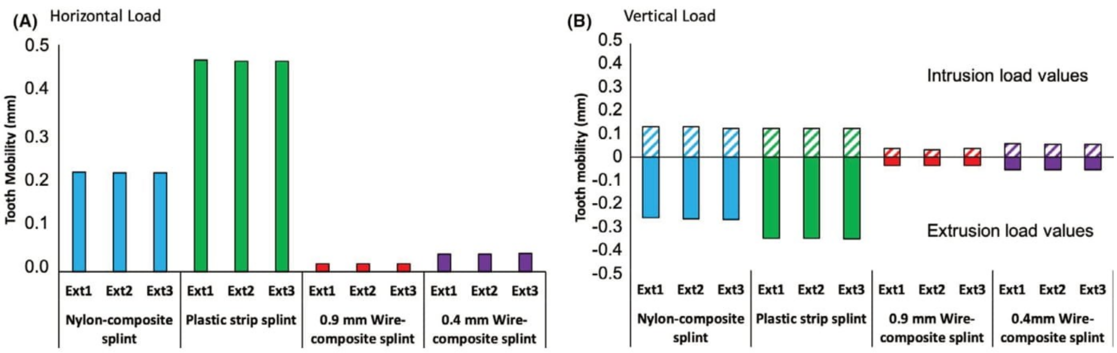

FIGURE 4 Avulsed tooth mobility measured after splinting with different splinting materials and extensions for 3 biting load types: (A) Biting load (1 N) applied horizontally to the avulsed tooth axis; (B) Biting load (1 N) applied perpendicularly to the tooth axis simulating an intrusive load (columns filled with diagonal strips) and an extrusive load (columns fully filled)

TABLE 2 Highest tooth mobility values during biting load

Splint Extension	Tooth Mobility (mm) Horizontal Load WCS1	WCS2	PSS	NCS	Intact unsplinted	Intrusive Load WCS1	WCS2	PSS	NCS	Intact unsplinted	Extrusive Load WCS1	WCS2	PSS	NCS	Intact unsplinted
Ext1	0.0164	0.0383	0.4644	0.2174	0.2464	0.0366	0.0579	0.1270	0.1327	0.0106	0.0366	0.0561	0.3593	0.2685	0.0106
Ext2	0.0167	0.0385	0.4645	0.2174		0.0309	0.0574	0.1270	0.1327		0.0367	0.0556	0.3593	0.2743	
Ext3	0.0176	0.0398	0.4668	0.2190		0.0368	0.0574	0.1270	0.1268		0.0368	0.0556	0.3603	0.2750	

in the NCS splint is a well-known material for dental splinting.[16] However, the 1.0 mm diameter is not commonly used despite reports demonstrating it being used with success.[31]

The extension of the splints had no effect on the mobility of the tested splints. The finite element simulation suggests that extending the splint to only one tooth on each side was enough to stabilize the injured tooth in its socket. However, extending a splint to more teeth or to the whole anterior arch might be an esthetic consideration. Especially in young patients, splints may be perceived negatively for social, functional, and emotional reasons.[32] Extending the splints over more teeth could also be considered as a fail-safe system. In case of debonding from the immediately adjacent teeth, where the highest stresses were seen (Figure 5), the replanted tooth would still maintain some stabilization from the other attachments that would still be present.

The models splinted with flexible materials showed higher stresses at the adjacent teeth than when splinted with the orthodontic wire. The more rigid orthodontic wire distributed the biting force better across all attachments, resulting in the slight differences in observed stresses.[33] The highest stress levels in this study were only around 5 MPa due to the low bite forces and are not expected to pose a high risk for debonding. Biting forces may increase, however, when healing progresses. The general stress distribution under horizontal loading in the splint attachment areas should remain similar regardless of the bite force, implying that if debonding did occur, this would most likely start at the occlusal edge of the attachments.

Splinting has been studied using various techniques. *In vitro* studies usually test the vertical mobility of splinted teeth using intrusive pressure.[34–36] This study showed that intrusive loading had similar performance for the two flexible splints (NCS and PSS). This was because the root reaching the apex of the alveolus limits the tooth mobility in this direction. However, the main reason for splinting avulsed teeth is to stabilize the tooth in the correct place, with adequate occlusal contact while avoiding accidental inhalation or ingestion.[11] When the avulsed tooth had no attachment, the more flexible splints (NCS and PSS) showed higher mobility in the extrusive direction.

Although the WCS2 splint is considered a flexible splint in different *in vitro* studies,[34,37] in this study the replanted avulsed incisor splinted with the WCS2 splint had more mobility than with the WCS1 splint, but still had stiffer behavior. This stiffness can be related to the low load application used in this study (1 N) compared with the different methods of mobility evaluation used in other studies, such as the Periotest and the universal testing machine, and lastly, to the PDL simulation. *In vitro* studies often simulate the PDL of the injured tooth with silicon materials or silicon associated with rubber foam, while the PDL of adjacent teeth is simulated with silicon.[7,11,15,34,37] This study simulated the deactivation of the PDL around the avulsed tooth. The absence of PDL support exacerbated the difference between the splint materials, showing displacement values close to the findings of the *in vitro* studies,[36,37] which validates the 3D simulations used in this study.

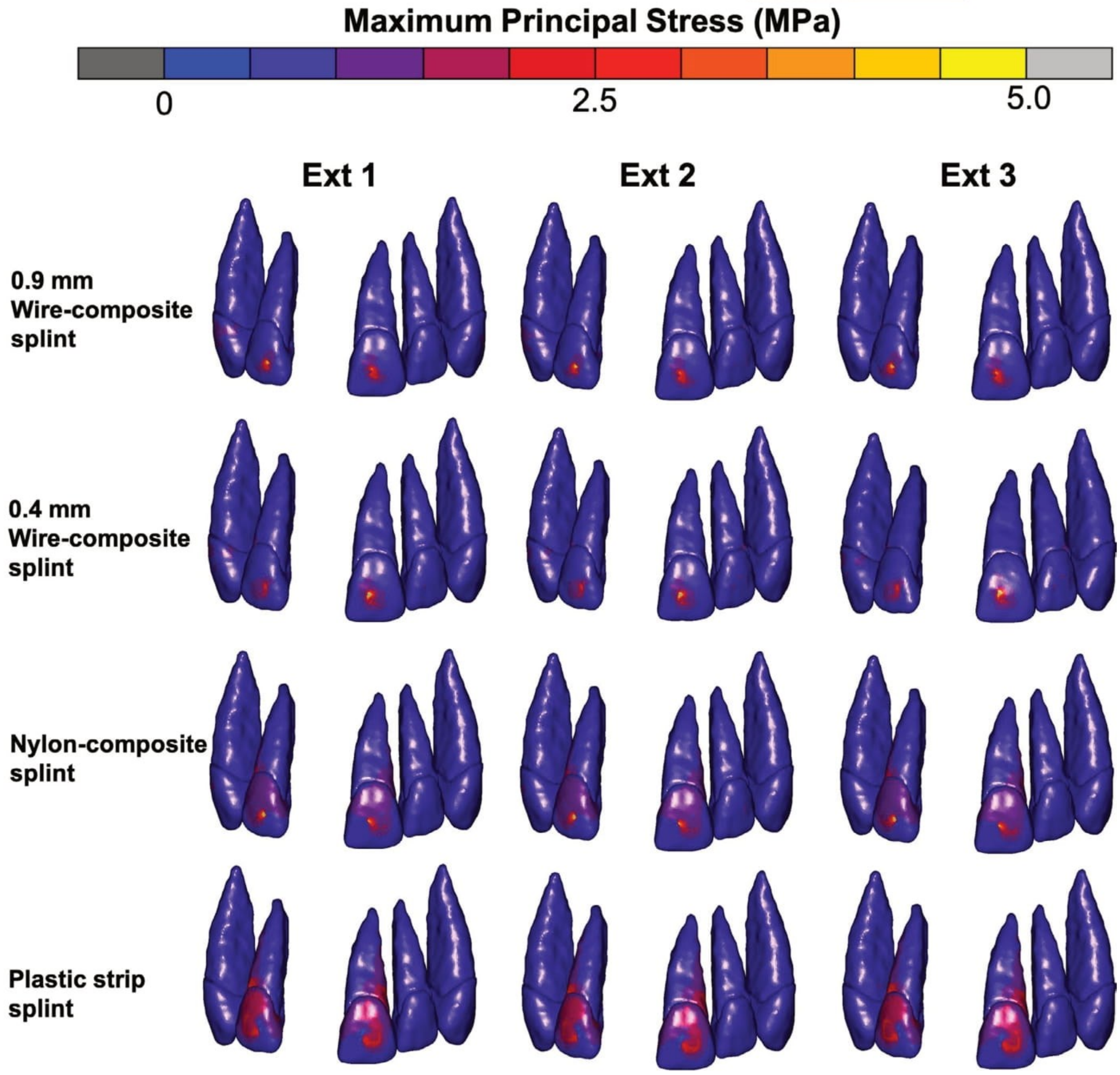

FIGURE 5 Maximum principal stresses on the labial surfaces of the adjacent teeth, where the splints were attached, during biting load application (1 N horizontal force on avulsed right central incisor) for the three different splint extensions (Ext 1, Ext 2, and Ext 3) and four splint types: 0.9 mm wire-composite splint; 0.4 mm wire-composite splint; nylon-composite splint; plastic strip splint

This patient-specific finite element analysis required some simplifications that could limit the breadth of the conclusions. All materials were considered isotropic and homogeneous, even though some oral tissues are known to have orthotropic properties, such as the enamel, or anisotropic heterogenous behavior, such as the bone. In addition, the mechanical properties of the PDL remain poorly understood and therefore difficult to simulate. Nevertheless, the simplifications adopted in this study are not expected to fundamentally alter the behavior of the tested splinting scenarios, and therefore, this analysis should help advance a better understanding of the role of splinting materials and extensions for a replanted avulsed tooth. Based on these results, splinting replanted teeth with WCS1 splints should be avoided, while splinting with WCS2 splints should be carefully analyzed, especially if the nylon-composite splint or plastic strip splint is available, in which case, these last two should be preferred. In addition, the guidelines for dental trauma avulsion injuries should consider the 1.0 mm NCS and the PSS as alternative flexible materials for splinting replanted avulsed teeth. Extending a splint beyond the adjacent two teeth does not necessarily improve stabilization, although it may still be a sound consideration as a fail-safe protection against potential debonding of a splint from a tooth which is adjacent to the injured tooth.

ACKNOWLEDGEMENTS

This study was supported by grants from PrInt-CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior), CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico), and FAPEMIG (Fundação de Amparo à Pesquisa de Minas Gerais). This study was carried out at the Biomechanics, Biomaterials and Cell Biology Research Center—CPBIO at UFU (Federal University of Uberlândia), and at the College of Dentistry of the University of Tennessee Health Science Center in Memphis, USA.

CONFLICT OF INTEREST

The authors confirm that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

Andomar Bruno Fernandes Vilela was involved in the generation of the models, data acquisition, literature search, data analysis, manuscript preparation, and manuscript editing. **Priscilla Barbosa Ferreira Soares** was involved in data analysis and manuscript editing. **Thiago Leite Beaini** involved in data analysis and manuscript editing. **Antheunis Versluis** was involved in conception and design, literature search, data acquisition, manuscript revision, and manuscript editing. **Carlos José Soares** was involved in conception and design, literature search, data analysis, manuscript editing, and manuscript revision. All the authors read and approved the final manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Andomar Bruno Fernandes Vilela https://orcid.org/0000-0003-2322-7067
Priscilla Barbosa Ferreira Soares https://orcid.org/0000-0002-4492-8957
Thiago Leite Beaini https://orcid.org/0000-0003-0034-624X
Antheunis Versluis https://orcid.org/0000-0003-0039-345X
Carlos José Soares https://orcid.org/0000-0002-8830-605X

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How to cite this article: Vilela ABF, Soares PBF, Beaini TL, Versluis A, Soares CJ. Splint stiffness and extension effects on a simulated avulsed permanent incisor—A patient-specific finite element analysis. Dental Traumatology. 2021;00:1–9. https://doi.org/10.1111/edt.12705

CAPÍTULO 2

Artigo aceito para publicação no periódico Dental Traumatology

Title: Dental trauma splints for mixed dentition – A finite element analysis of splint material, splint extension, missing teeth, and PDL

Andomar Bruno Fernandes Vilela[a], Priscilla Barbosa Ferreira Soares[b], Antheunis Versluis[c], Carlos José Soares[a]

[a] Department of Operative Dentistry and Dental Materials, Dental School, Federal University of Uberlândia, Uberlândia, Minas Gerais, Brazil.

[b] Department of Periodontology and Implantology, Dental School, Federal University of Uberlândia, Uberlândia, MG, Brazil.

[c] Department of Bioscience Research, College of Dentistry, University of Tennessee Health Science Center, Memphis, Tennessee.

Running Title: Splint extension on mixed dentition

Keywords: edentulous area, missing tooth, flexible splint, splint span, splint extension, displacement

ACKNOWLEDGMENTS

This study was supported by grants from PrInt-CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior), CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) and FAPEMIG (Fundação de Amparo à Pesquisa de Minas Gerais). This study was carried out at the Biomechanics, Biomaterials and Cell Biology Research Center – CPBIO at UFU (Federal University of Uberlândia), and at the College of Dentistry of the University of Tennessee Health Science Center in Memphis, USA.

AUTHOR CONTRIBUTIONS

Andomar Bruno Fernandes Vilela: Models Generation, Data Acquisition, Literature Search, Data Analysis, Manuscript Preparation and Manuscript editing. **Priscilla Barbosa Ferreira Soares:** Data analysis, Manuscript editing. **Antheunis Versluis**: Conception and Design, Literature Search, Data Acquisition, Manuscript Revision and Manuscript Editing. **Carlos José Soares**: Conception and Design, Literature Search, Data analysis, Manuscript Editing and Manuscript Revision.

All the authors read and approved the final manuscript.

ORCID

Andomar Bruno Fernandes Vilela: https://orcid.org/0000-0003-2322-7067

Priscilla Barbosa Ferreira Soares: https://orcid.org/0000-0002-4492-8957

Antheunis Versluis: https://orcid.org/0000-0003-0039-345X

Carlos José Soares: https://orcid.org/0000-0002-8830-605X

Corresponding author:

Dr. Carlos José Soares

Federal University of Uberlândia, School of Dentistry

Avenida Pará, 1720, Bloco 4L, anexo A, sala 42, Campos Umuarama.

Uberlândia, Minas Gerais, Brazil

Zip-Code: 38400-902

E-mail: carlosjsoares@ufu.br

Phone: +55 34 999713472

ABSTRACT

Background/Aims: Dental trauma injuries are common in children during mixed dentition. These injuries usually require splinting for stabilization, which is complicated by the stages of permanent tooth developments and primary tooth exfoliations. This evaluated the effect on mobility of splint materials and extensions for an avulsed central incisor, stabilized with and without the adjacent incisor under intrusive and extrusive loading under different periodontal ligament (PDL) conditions.

Materials and Methods: Seventeen 3D model variations were created from a CBCT scan of a 7-year-old patient without erupted permanent upper lateral incisors. A 1000N palatal load on the right central incisor simulated the avulsion injury and created an increased alveolus and bone deformation, resulting in an increased PDL thickness of 0.45mm. Wire-composite splints with 0.9mm cross-section (WCS) or 1.0mm diameter nylon-resin composite splints (NCS) were created. The models simulated conditions with and without the adjacent upper central incisor. Two PDL conditions were investigated, simulating liquefied PDL or PDL with silicon properties. Mobility was calculated under simulated biting loads in horizontal and vertical (intrusive and extrusive) directions.

Results: The NCS allowed higher tooth mobility of the avulsed incisor than the WCS, irrespective of extension, PDL condition, or load application. During horizontal loading, silicon-like properties for the PDL allowed around 0.2mm mobility of the avulsed tooth with the WCS, similar to the intact tooth, whereas a simulated liquefied PDL allowed 25% higher mobility with a WCS than NCS.

Conclusions: A 1.0mm NCS seems a good option for splinting avulsion injuries during mixed dentition compared to the considerably more rigid WCS. The NCS provided flexibility for PDL healing while maintaining stability, even when missing adjacent teeth increased span widths. Extensions beyond directly adjacent teeth did not alter mobility with the NCS, but should still be considered an extra protection in case of bond failure or exfoliation.

INTRODUCTION

More than 25% of dental trauma cases during mixed dentition involve central incisors.[1,2] These events can lead to serious injuries, such as avulsion, considered one of the most harmful and common wounds.[2] The treatment of avulsed teeth requires complex procedures, including splinting.[3] Splinting aims to maintain an injured tooth in its correct position, prevent aspiration, and protect it against harmful forces.[4]

Studies involving permanent dentition recommend splinting the injured tooth to one[5-7] or two uninjured teeth bilaterally.[3,8] However, during mixed dentition, 7-8 years old children are frequently changing primary teeth, leading to empty spaces, such as the upper lateral incisors. In this situation, increasing the splint extension has been recommended,[9] although there is no clear established protocol. To perform dental splints in mixed dentitions, clinicians have been led by empirical evidence, such as case reports.[10-14] Different dental splint materials have been described for first aid treatment of dental trauma injuries.[15] Wire-composite splints (WCS), using metallic wires above 0.45mm are one of the most commonly mentioned for rigid fixation, while nylon-composite splints (NCS) are known as flexible splints.[16,17] However, little is known about the effect of these materials in mixed dentitions when adjacent teeth are missing.

Testing the performance of splint designs is most commonly performed in vitro. Since splint effectiveness is directly related to tooth mobility, the representation of the periodontal ligament (PDL) behavior is a critical study design element that can affect the conclusions.[21] Published in vitro studies have simulated the PDL using silicon,[6,18] silicon and rubber foam,[5,15] or sometimes do not report how PDL was simulated.[7,19] Finite element analysis (FEA) has often been used to understand the biomechanical behavior in complex structures,[22,23] including splints.[24,25] FEA seems well suited to test the effect of different splinting materials and extensions on tooth mobility because structures and properties can be precisely and consistently defined.

To the best of the authors' knowledge, no study has tested the biomechanics of extensions of dental trauma splints in mixed dentitions. Therefore, the aim of this study was to evaluate the displacement of an avulsed central incisor in mixed dentition, with and without adjacent central incisor, stabilized with different extensions of flexible and rigid splints for different PDL assumptions. The null hypothesis tested was that the splint material, splint extension, presence or absence of the adjacent permanent incisor, and PDL tissue conditions would not affect the mobility of an avulsed central incisor.

MATERIALS AND METHODS

Three-dimensional (3D) model segmentation

This study was carried out with three-dimensional numerical modeling and simulation, based on a maxillary cone-beam computer tomography (CBCT) scan from a 7-year-old patient, with 14 permanent teeth, between erupted and under development, and 8 primary teeth. This CBCT was chosen from the bank of images from the Federal University of Uberlândia that were performed for diagnosis purposes of a supernumerary lateral incisor. This study was conducted following the Declaration of Helsinki of ethical principles for medical research involving human subjects and was approved by the local ethics committee with protocol number 1.776.692.

The CBCT was imported to a medical image-based engineering software (Mimics 22.0, Materialise Dental, Leuven, Belgium) for segmentation of the maxillary bone (cortical and trabecular), enamel, dentin, and connective tissue of the permanent tooth germ (Figure 1 A and B). Different thresholds with manual editions and corrections performed this segmentation automatically. The periodontal ligament (PDL) was created by Boolean operations in each tooth. This operation was performed by expanding pixels of the dentin followed by subtraction of the initially segmented dentin, creating a 0.25 mm PDL layer.

The models simulating all the structures in the CBTC (Figure 1C), segmented structures as an inhomogeneous mesh (Figure 1D), were then exported separately to 3-Matic software (Materialise, Belgium) to create a continuous volumetric mesh of triangular tetrahedral elements with a 0.2 mm target size (Figure 1E).

The different structures were then joined for the splint design. A point perpendicular to the central area of the buccal surface of the crowns of each erupted tooth was selected, creating a curve following the maxillary arch curvature. This curve was then converted into a 1.0 mm diameter bar to simulate a fishing line or a 0.9 mm tall beam for an orthodontic wire. The composite resin blocks were created with a 3-mm square shape with rounded edges. A Boolean operation was performed by subtracting the splints from the composite resins, creating the fit between the mesh of both structures. The composite splints were moved towards the buccal surface of the crowns and another Boolean operation was performed between the composite resin and the enamel of each tooth to avoid overlapping or inside-out elements (Figure 1F). All material and tissue interfaces in the models were continuous.

Avulsion simulation

The patient-specific 3D digital anatomical model was imported to a finite element analysis (FEA) software (MSC.Marc, MSC.Software, Palo Alto, CA, USA) to perform the structural analysis (Figure 2A). Four-node isoparametric arbitrary distorted tetrahedron elements were used (element type 134 in the MSC.Marc software). All materials were considered linear-elastic, isotropic, and homogeneous. The material properties are shown in Table 1.[26-34] The model was held in place by fixing nodes on the top and lateral sides of the bone in X- Y- and Z- directions (Figure 2D).

An initial FEA simulation was performed to create an avulsion injury. A high nodal load of 1000 N was applied in palatal direction on the maxillary permanent right central incisor in three nodes on the palatal surface, from the mesial to distal side, 333.3 N per node (Figure 2B). This deformed the buccal alveolar bone. The bone deformation was made permanent using a custom subroutine, resulting in a widened alveolus socket and an increased thickness of the periodontal ligament of up to 0.45 mm (Figure 2C). The new models with the avulsion injury were made stress-free for subsequent analyses.

Seventeen 3D model variations of the mixed dentition were created: sixteen with the avulsion injury and one with the intact condition. Three factors were studied (Figure 3):

(1) Splinting materials: The splinting of the injured tooth was simulated using two materials: **NRcS**, 1.0 mm diameter fishing line (Dourado, São Bernardo do Campo, SP, Brazil); **WRcS**, 0.9 mm rigid wire (Morelli Ortodontia, Sorocaba, SP, Brazil). Both splints were fixed to the teeth with resin composite (Filtek Z350XT, 3M ESPE, St Paul, MN, USA).

(2) Splinting extension: 4 splinting extensions were simulated: **Can-Can**, Splinting from canine to canine; **1ºPm-1ºPm**, Splinting from the left first primary molar to the right first

primary molar; **2ºPm-2ºPm**, Splinting to the left second primary molar to the right second primary molar; **1ºPeM-1ºPeM**, Splinting to the left first permanent molar to the right first permanent molar.

(3) Presence of adjacent central incisor: two conditions were simulated: **NoAdI**, Without the adjacent central incisor, which was avulsed and missing (Figure 3A); **WAdI**, With the presence of an adjacent intact central incisor (Figure 3B).

PDL simulation and load application

After avulsion simulation, the splint was activated and two PDL conditions of the avulsed tooth were simulated: Liq-PDL, simulating the liquefied tissue and absence of PDL attachment; and S-PDL, simulating PDL tissue with silicon properties. No-PDL was simulated by deactivating the PDL tissue in the analysis.

Horizontal (perpendicular to the tooth axis) and vertical (parallel to the tooth axis) biting loads were simulated on the palatal side of right permanent central incisor. Both intrusive and extrusive vertical loads were tested. The applied loads were single point loads, 50 N for the S-PDL models, and 1 N for the No-PDL models. The low 1 N biting load on the unsupported avulsed tooth can be considered the condition where a patient decreases the biting load on an injured tooth.[35] The mobility of the avulsed tooth in that condition is borne solely by the splint. A custom-made subroutine collected the displacements of the permanent avulsed tooth during the load application. To isolate tooth displacement from socket displacements, socket displacement was subtracted from the overall mobility values. Socket displacement was determined in its notional ‘center-of-resistance’, defined along the longitudinal socket-axis, two-thirds the length from the socket apex to the height of the enamel-cement junction.

RESULTS

The horizontal and vertical tooth mobility of the avulsed central incisor with No-PDL and S-PDL for each type of splint material and extensions with and without adjacent tooth are shown in Figures 4 and 5.

Comparing the S-PDL groups, the NCS allowed higher tooth mobility of the injured tooth compared to the WCS, irrespective of splinting extension and the presence of the adjacent central incisor. The splint extension did not influence the NCS models. However, increasing the extension of the WCS decreased the mobility of the avulsed tooth. All models splinted with the adjacent intact central incisor had lower mobility of the avulsed tooth, except when NCS was used. When the adjacent permanent central incisor was absent, splinting the avulsed tooth from canine to canine (Can-Can) with WCS resulted in tooth mobility similar to the intact tooth. The WCS splinted injured tooth has similar mobility as the intact tooth for both adjacent incisor conditions (Figure 4A). The simulation of the vertical biting load parallel to the tooth axis (intrusion and extrusion) is shown in Figure 4B. The NCS splint allowed higher mobility than the intact tooth, irrespective of splint extension, loading conditions, or presence of adjacent central incisor. The tooth mobility of the avulsed tooth in all simulated conditions is shown in Table 2.

In the case of a simulated liquefied PDL condition, the different splint extensions did not influence the splint behavior. However, increased tooth mobility of the avulsed tooth for both horizontal and vertical directions was observed compared with the S-PDL group (Figure 5). The No-PDL group experienced 4x higher tooth mobility in horizontal direction than the S-PDL. Splinting the avulsed tooth with NCS when No-PDL was simulated resulted in higher tooth mobility, while the WCS splint reduced tooth mobility by more than 90%. The absence of the adjacent permanent central incisor also increased the tooth mobility of the avulsed tooth, maintaining the same behavior demonstrated when S-PDL was simulated. The highest tooth mobility was found for the NCS splint group with No-PDL simulation.

DISCUSSION

The null hypothesis was rejected. The splinting material, the splint extension, the presence/absence of the neighboring intact permanent central incisor, and PDL representation affected the mobility of the avulsed tooth in various, often interactive, ways. The demonstrated relationships can help clinicians in selecting the best splinting configurations for mixed dentitions.

In the selection of a stable splinting configuration, maintaining some flexibility is an important consideration. Flexibility allows the physiological mobility essential for PDL repair.[36] The IADT guidelines suggest the use of nylon-composite splints of 0.25 mm for treatment of avulsion injuries in permanent dentitions, but the guidelines do not recommend it for mixed dentitions with missing teeth.[4] In edentulous areas, reinforced nylon-composite splints have been proposed as well as extensions.[9] This FEA study therefore increased the thickness of the nylon-composite splint to 1.0 mm and tested it for different extensions against a more rigid wire-composite splinting option.

The analysis indicated that extensions to canines, 1st primary premolar, 2nd primary premolar, or permanent molar, had no effect on the mobility achieved by the flexible nylon-composite splint. In combination with the stiffer wire-composite splint, extensions only slightly decreased mobility. Similar outcomes have been reported in other studies.[5,37] The current study demonstrated, however, that the adjacent permanent central incisor played an important role in stabilizing the avulsed incisor because it provided a nearby anchor point for the splint. This was especially evident with the nylon-composite flexible splint. The analysis indicated that splint material choice (nylon or wire) and the presence of an intact adjacent tooth had more effect on the mobility of the avulsed incisor than the number of extensions. Since flexible splints are recommended for PDL recovery,[4] the relative distance of splint support rather than the number of extensions can be expected to have more direct clinical consequences for mixed dentitions. Splinting during mixed dentition is a delicate procedure because physiological root resorption of primary canines and molars can be expected during this treatment phase. To prevent splinting to teeth with advanced physiological root resorption, splint spans may have to be longer by the need to extend from primary canines to posterior teeth.

This study also demonstrated the importance of splint spans, which is the spacing of the splint anchor points. Especially during in the early stage after an avulsion injury, when the PDL is liquefied, the mobility of the nylon-composite splinted injured incisor was considerably higher if the adjacent central incisor was missing. In case of a missing adjacent permanent central incisor, a mini-implant with temporary prosthesis has been suggested to be placed as an anchor point,[38,39] although such rather drastic route may need further study. Splinting the avulsed incisor with a flexible nylon-composite splint to the primary canine when the near adjacent central incisor is present seems enough to stabilize the injured tooth. In case of physiological root resorption of the canines, the splint span should also include the first primary premolar because although extensions will not increase the stability for flexible splints, they overcome the limitation of only bonding to nearby canines and secure stability in events where attachments are lost due to exfoliation or bond failure.

The recommendations in this study were based on a finite element analysis. For practical and ethical reasons, in vitro and in silico tests are the most appropriate methods to assess the behavior of different splinting options before they are applied clinically. Both approaches, however, face choices and simplifications in modeling the physical and anatomical conditions. In vitro studies often use silicon material to represent PDL tissue. In this FEA study, the results obtained with a PDL featuring silicon properties were found to be similar to an in vitro study, showing that extensions decreased mobility for rigid splints but had no effect on flexible splints .[5] This behavior, which can be explained by the fact that rigid splints involve all connected teeth while flexible splints only involve the closest supports, confirmed the general validity our models. Using the same analysis, but now with PDL modeled as a non-supportive (liquefied) tissue, this study showed that PDL properties can significantly alter the conclusions about splint design and extension choices. Where a silicon-like PDL suggested relatively minor differences when extending a splint across an adjacent open tooth space, mobility was greatly affected if the PDL was unsupportive. Under clinical conditions, during the first aid consultation, a socket is filled with blood and provides little support to the injured tooth. The authors therefore believe that the evaluation of splints using silicon could lead to unrepresentative results. In vitro tests should therefore consider using less supportive foam or leave the apex unsupported for better simulation of the clinical conditions of an injured tooth.

Another important consideration for in vitro and in silico studies, besides the PDL properties, is the need to replicate the anatomical conditions. For in vitro studies it is particularly difficult to simulate a mixed dentition, with its specificities such as an open apex of permanent teeth, physiological root resorption of primary teeth, and the relationships between primary teeth and developing permanent. This FEA study used a 3D patient-specific model of an actual infant to shape the complex anatomy and simulate the tissue connections. Even within the limitations of incomplete understanding of all tissue-property relationships, this approach is most likely to reveal the general biomechanical performance and stabilization characteristics among dental splint options, and help guide clinicians in their splint selection for the best care for their patients.

CONFLICT OF INTEREST STATEMENT

The authors confirm that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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TABLES

Table 1. Material properties applied in the finite element analysis.

Structures	Elastic Modulus (MPa)	Poisson Ratio	References
Enamel	84,100	0.30	(26)
Dentin	18,600	0.30	(27)
Periodontal Ligament	50	0.45	(28)
Cortical Bone	13,700	0.33	(29)
Trabecular Bone	1,400	0.31	(29)
Connective Tissue	1,8	0.30	(30)
Polyether	2,290	0.30	(31)
Nylon wire	2,700	0.30	(32)
Orthodontic wire	200,000	0.30	(33)
Composite Resin	18,500	0.24	(34)

Table 2. Tooth displacement (mobility) values during simulated biting load.

			Mobility values (mm)					
Groups	Adjacent incisor condition	Splint extension	**Horizontal Load S-PDL (50N)**	**Extrusion S-PDL (50 N)**	**Intrusion S-PDL (50 N)**	**Horizontal Load No-PDL (1 N)**	**Extrusion No-PDL (1 N)**	**Intrusion No-PDL (1 N)**
Intact			0.3333	-0.0514	0.0514	---	---	---
NCS	With adjacent central incisor	Perm. Molar	0.4198	-0.0351	0.0329	0.2381	-0.6516	0.7682
		2nd Prim. Molar	0.4199	-0.0351	0.0329	0.2381	-0.6516	0.7682
		1st Prim. Molar	0.4202	-0.0351	0.0330	0.2386	-0.6519	0.7682
		Canines	0.4203	-0.0351	0.0330	0.2386	-0.6519	0.7682
	Without adjacent central incisor	Perm. Molar	0.4263	-0.0351	0.0337	1.2529	-2.8919	3.6415
		2nd Prim. Molar	0.4263	-0.0351	0.0337	1.2570	-2.8919	3.6415
		1st Prim. Molar	0.4267	-0.0351	0.0337	1.2576	-2.8919	3.6415
		Canines	0.4267	-0.0351	0.0337	1.2588	-2.8919	3.6415
WCS		Perm. Molar	0.2340	-0.0113	0.0100	0.0062	-0.0201	0.0045

With adjacent central incisor	2nd Prim. Molar	0.2566	-0.0136	0.0123	0.0070	-0.0202	0.0043
	1st Prim. Molar	0.2972	-0.0184	0.0169	0.0092	-0.0204	0.0037
	Canines	0.3076	-0.0197	0.0182	0.0098	-0.0205	0.0036
Without adjacent central incisor	Perm. Molar	0.2913	-0.0177	0.0160	0.0210	-0.0548	0.0420
	2nd Prim. Molar	0.3084	-0.0193	0.0177	0.0220	-0.0545	0.0420
	1st Prim. Molar	0.3423	-0.0229	0.0211	0.0254	-0.0550	0.0426
	Canines	0.3571	-0.0249	0.0231	0.0284	-0.0551	0.0426

FIGURE LEGENDS

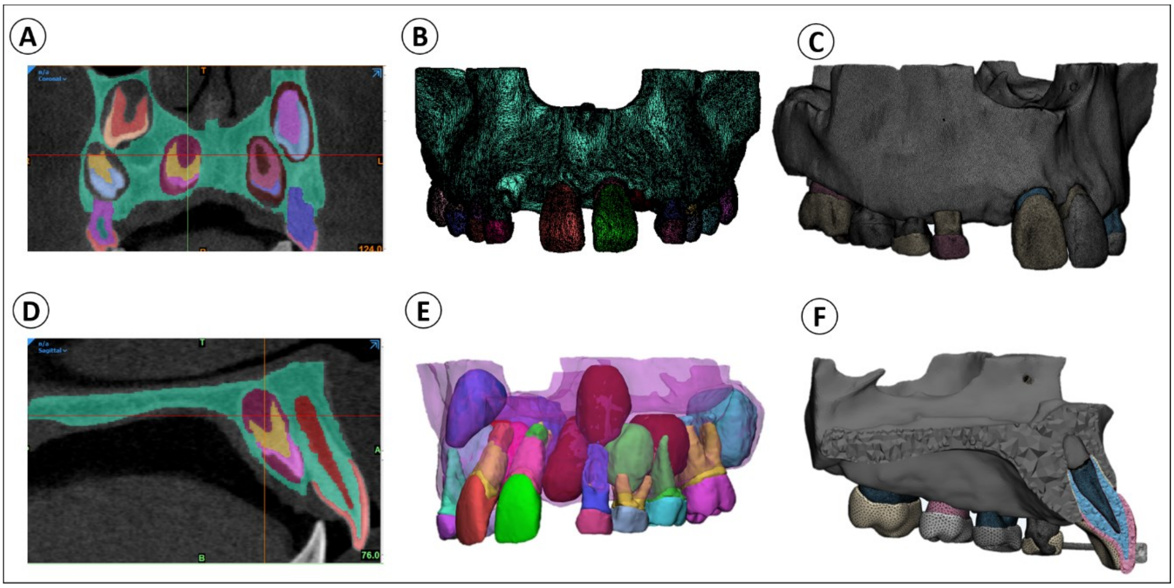

Figure 1. Segmentation of the different maxillary structures of a 7-year-old child with mixed dentition: A, CBCT scan in Mimics software segmentation in axial tomographic cut visualization; B, Mimics software segmentation on with sagittal tomographic cut; C, irregular and inhomogeneous mesh created in Mimics software; D, The 14 maxillary permanent teeth in development and the six primary teeth erupted and under physiological root resorption; E, Final and organized external mesh with 0.15 mm element target size; F, Volumetric mesh of the different structures and the splint simulation performed in 3-Matic software.

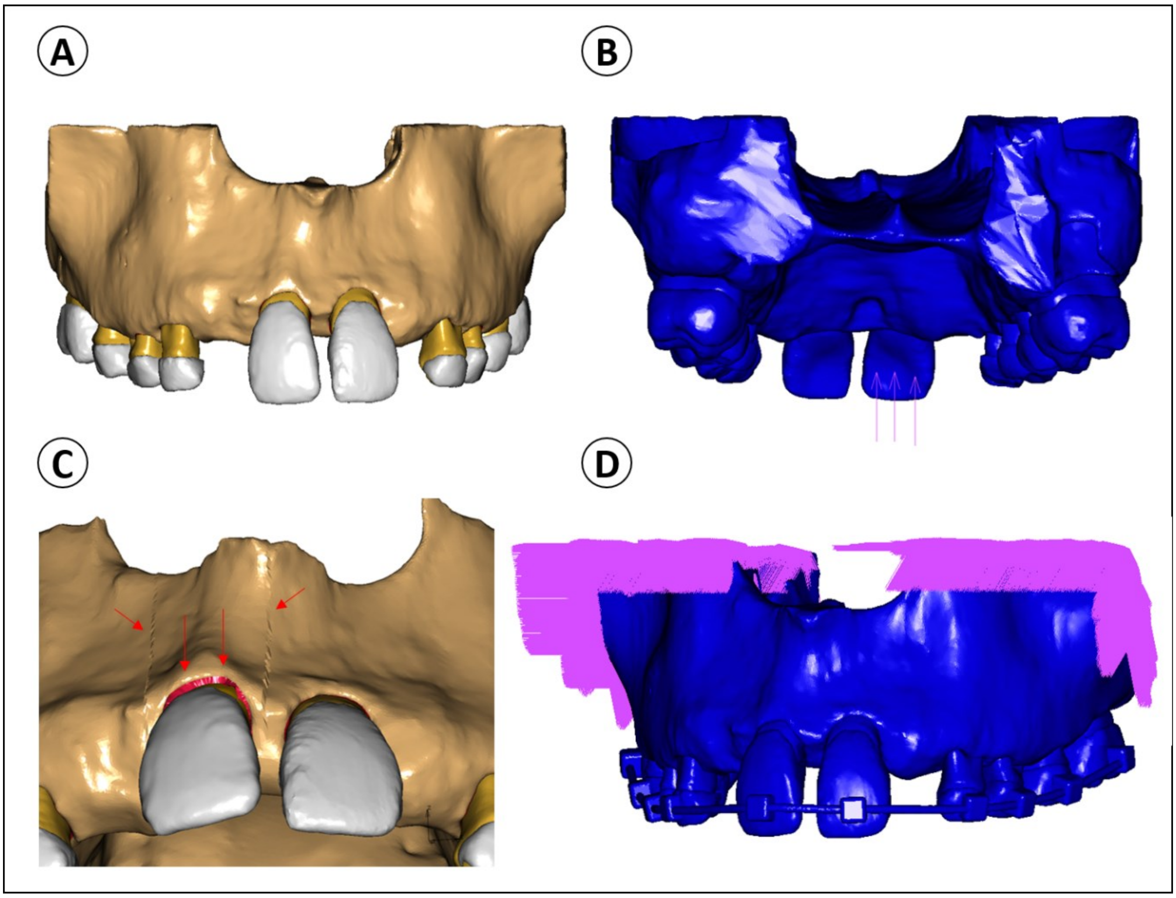

Figure 2. Avulsion simulation and load application; A; intact maxillary model before avulsion; B, 1000 N total load application on three nodes at the palatal area of the right upper central incisor; C, bone deformation at the buccal side of the bone caused by the traumatic load and the 0.45 mm resulting PDL thickness increase, indicated by arrows; D) splint activation and fixed boundary conditions, restricting X-, Y- and Z-movement of nodes on the top and lateral area of the maxilla.

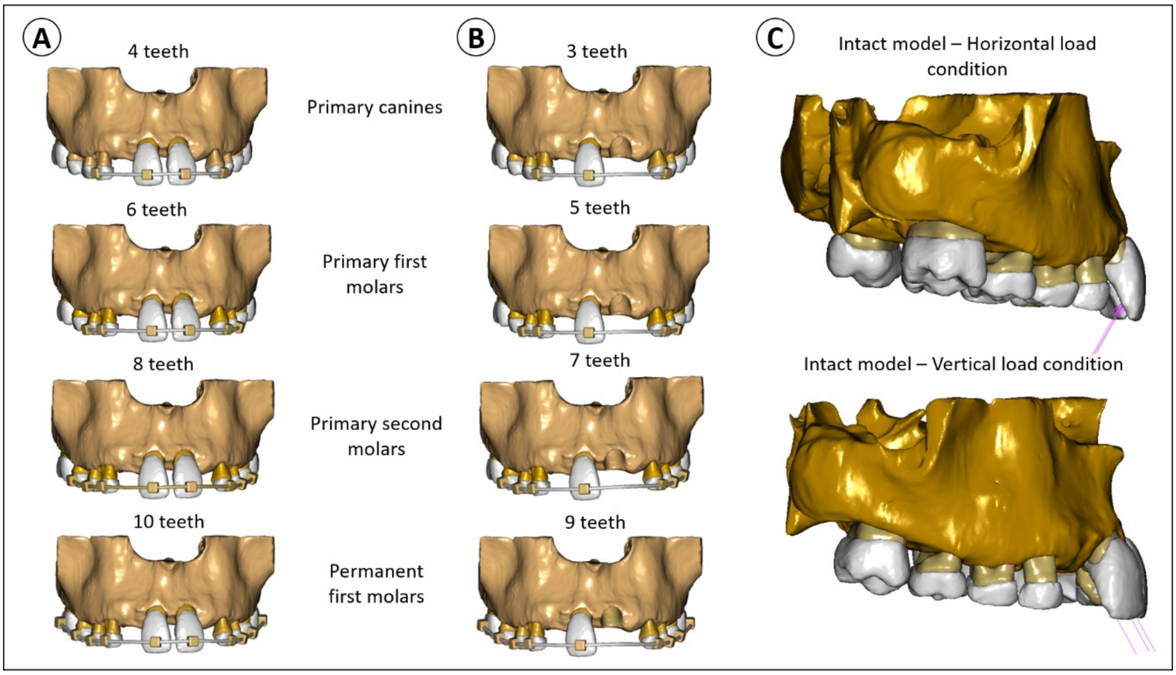

Figure 3. The 3D models with the various splint extensions and adjacent central incisor conditions; A, without an adjacent central incisor; B, with an intact adjacent central incisor; C, applied horizontal and vertical (extrusion and intrusion) loads indicated by arrows.

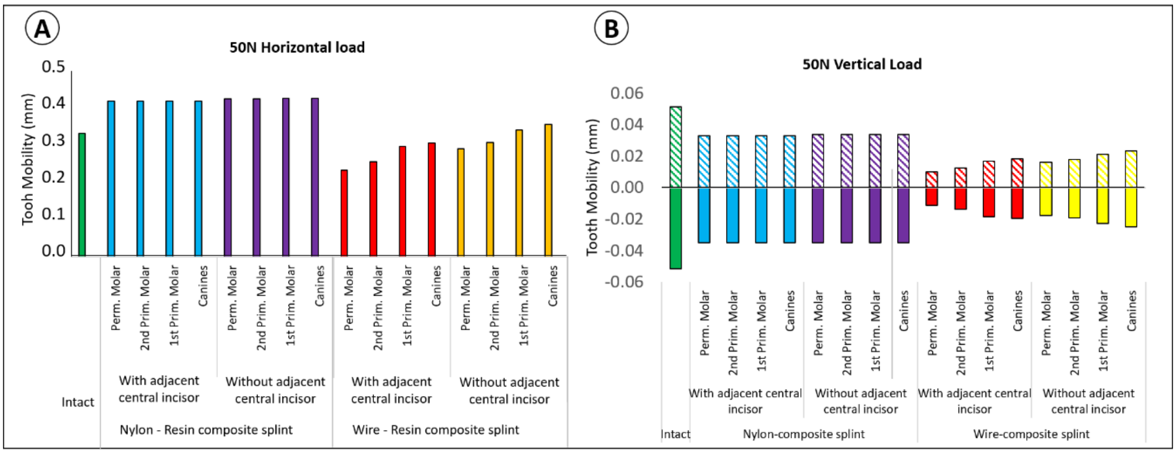

Figure 4. Tooth mobility values of the avulsed right central incisor with silicon-like properties (S-PDL); A, horizontal mobility with 50 N horizontal load application; B, vertical mobility values (extrusion and intrusion) with 50 N load application in the direction of the tooth long axis.

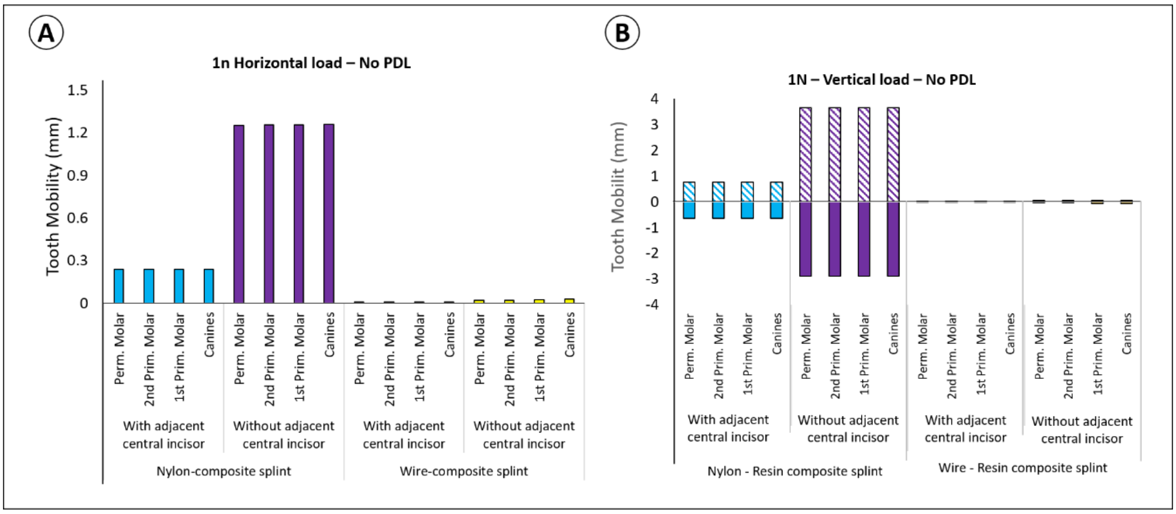

Figure 5. Tooth mobility values of the avulsed right central incisor for an unsupportive PDL, simulating the absence of PDL attachment (No-PDL); A, horizontal mobility measured of the avulsed central incisor with 1 N horizontal load application; B, vertical mobility values (extrusion and intrusion) with 1 N load application in the direction of the tooth long axis.

CAPÍTULO 3

Artigo a ser submetido no periódico Dental Traumatology

Title: Evaluation of Fluorescence-aided Identification Technique (FIT) with different lighting sources and rotatory instruments for dental trauma splint removal

Andomar Bruno Fernandes Vilela[a], Priscilla Barbosa Ferreira Soares[b], Fernanda Silva Gonçalves [a], Guilherme de Araújo Almeida[c], Carlos José Soares[a].

[a] Department of Operative Dentistry and Dental Materials, Dental School, Federal University of Uberlândia, Uberlândia, Minas Gerais, Brazil.

[b] Department of Periodontology and Implantology, School of Dentistry, Federal University of Uberlândia, Minas Gerais, Brazil.

[c] Department of Orthodontics, School of Dentistry, Federal University of Uberlândia, Minas Gerais, Brazil.

Running title: Assessing resin remnant removal and enamel damage

Keywords: semi-rigid splint; resin removal; violet light; 3D evaluation; zirkonzahn.

ACKNOWLEDGMENTS

This study was supported by grants from PrInt-CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior), CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) and FAPEMIG (Fundação de Amparo à Pesquisa de Minas Gerais). This study was carried out at the Biomechanics, Biomaterials and Cell Biology Research Center – CPBIO at UFU (Federal University of Uberlândia), and at the College of Dentistry of the University of Tennessee Health Science Center in Memphis, USA.

AUTHOR CONTRIBUTIONS

Andomar Bruno Fernandes Vilela: Models Generation, Data Acquisition, Literature Search, Data Analysis, Manuscript Preparation and Manuscript editing. **Priscilla Barbosa Ferreira Soares:** Data analysis, Manuscript editing. **Antheunis Versluis**: Conception and Design, Literature Search, Data Acquisition, Manuscript Revision and Manuscript Editing. **Carlos José Soares**: Conception and Design, Literature Search, Data analysis, Manuscript Editing and Manuscript Revision.

All the authors read and approved the final manuscript.

ORCID

Andomar Bruno Fernandes Vilela: https://orcid.org/0000-0003-2322-7067

Priscilla Barbosa Ferreira Soares: https://orcid.org/0000-0002-4492-8957

Antheunis Versluis: https://orcid.org/0000-0003-0039-345X

Carlos José Soares: https://orcid.org/0000-0002-8830-605X

Corresponding author:

Andomar Bruno Fernandes Vilela

Federal University of Uberlândia

School of Dentistry

Avenida Pará, 1720, Bloco 4L, Anexo A, Sala 42, Campus Umuarama.

Uberlândia - Minas Gerais – Brazil CEP. 38400-902

Email: andomar@ufu.br

Phone: +55 (901) 338-2438

Evaluation of Fluorescence-aided Identification Technique (FIT) with different lighting sources and rotatory instruments for dental trauma splint removal

ABSTRACT

Background/Aim: Removal of composite resin used for bonding dental trauma splint may result in irreversible damage to enamel. The aim of this in vitro study was to evaluate the influence of additional illumination and different bur types on the generation of damage to tooth enamel.

Materials and Methods: Fifteen maxillary models with four bovine teeth were generated. All models were scanned, using a laboratory scanning systems (s600 ARTI; Zirkonzahn). After a flexible nylon splint was created using etch-and-rinse adhesive and fluorescence resin composite. One operator removed all splinting. The 6 groups experimental groups (n=10) were generated by 2 study factors: lighting type (1. low cost violet light; 2. VALO cordless with violet filter; or 3. without additional illumination) and rotatory instrument (1. diamond bur; or 2. multifluted tungsten-carbide bur). A new scanning was performed and superimposed on the initial scan using Cumulus software. A qualitative and quantitative analysis of enamel loss was performed and statistically analyzed. Two-way ANOVA and Tukey's post-hoc test were used at a 5% significance level.

Results: The use of violet lighting presented in low-cost violet flashlight and VALO Cordless resulted in significantly lower damage on enamel surface than the groups without additional violet light ($P < 0.001$). There were no statistical difference between low-cost flashlight and VALO Cordless. However, an interaction between rotatory instrument and lighting was found, when no additional violet lighting was used.

Conclusions: Fluorescence lighting facilitated the removal of remnant composite resin used in dental trauma splints, leading to less invasive treatment. The diamond bur presented higher enamel depth values when no additional violet light was used.

Introduction

The high prevalence of dental trauma, represented by more than one billion cases worldwide, (1) with a high incidence on young patients every year, emphasizes dental trauma as an important public health matter. (2) When the injury causes damage to periodontal tissues, the flexible stabilization is important. (3) A nylon-composite splinting is a well known flexible stabilization method that allows the physiological movement of the traumatized teeth, achieving expected periodontal repair, (4-6) and it is commonly used due to its esthetic and low cost material. (7)

The nylon-composite resin splint are usually applied on the buccal surface of the teeth, (4) however, its use is temporary, (5) and after the period of periodontal ligament healing, the line and the composite resin remnant needs to be removed, and this procedure, might cause damage on the enamel surface. (8) The proper method to perform the composite resin removal is still inconclusive, and when performed incorrectly, can lead to irreversible wear of the enamel. The enamel damaged can increasing surface roughness, causing greater biofilm accumulation and promoting tooth darkening. (9)

Several methods have been described to remove the dental splints and more specifically, for the remaining composite resin on the enamel surface, including the use of multifluted tungsten and diamond burs. (10) In addition, the use of violet light has been reported as an important aid in removing orthodontic adhesives from the enamel surface.

(11) The use of multiplier counter-angle associated with multifluted burs in the removal of remnant composite resin is known to be the most effective method for preserving the structure of healthy enamel during the removal of composite resins. (12, 13) However, without using additional light, this method can still cause damage to the enamel structure, which can range from 0.05, (12) to 50 µm (14).

Due the absence of a clear protocol to assist the clinician in this complex procedure, this study aimed to investigate the effect of additional illumination, with violet light presence in multiwavelength light-emitting diode or the use of low-cost intraoral lanterns, associated with the use of diamond or multifluted burs in low-speed in the preservation of iatrogenic damage to the enamel in dental splint removal. The null hypotheses were that light source and bur type would not influence the enamel damage caused after splinting removal.

Materials and methods

Development of new artificial models

Sixty sound bovine incisors with similar dimensions were randomly selected, cleaned and stored in distilled water at 5^{o}C temperature. A wax model (Wilson, Polidental Indústria e Comércio Ltda, Cotia, Brazil) was created simulating the anterior maxilla region with four alveoli. Fifteen impressions were made from the wax model using vinyl polyvinylsiloxane impression material (Aerojet, São Paulo, Brazil). After 24 h the mandible was removed, leaving its impression in the polyvinylsiloxane mold and the maxillary anatomy was reproduced in polystyrene resin (Aerojet, São Paulo, Brazil). The enamel buccal surface of the bovine teeth was sequentially ground on wet #600, #1000, #1200 and #1500-grit silicon carbide abrasive papers (Norton, Campinas, SP, Brazil) to achieve a flat surface. Then, the teeth were polished with polishing cloths (Stuers, Erkrat, Germany) with 6µm, 3µm, 1µm, 1/4µm diamond pastes (Arotec, Cotia, SP, Brazil). Fifteen maxillary models were produced, and these collected teeth, were inserted into the artificial alveoli, simulating a clinical situation of four upper incisors (Figure 1).

Dental Splinting

The buccal surface of the bovine enamel was etched for 30s with 37% phosphoric acid (Condac 37%, FGM Produtos Odontológicos, Joinville, SC, Brazil), rinsed with water for 30 s and dried, followed by the application of a 10 second photoactivation adhesive (Ambar, FGM) using a VALO Cordless multi-spectrum LED (Ultradent, South Jordan, UT, USA) at the standard mode with irradiance of 1400 mW/cm^2. A high fluorescent conventional nanoparticulate composite resin (Vittra APS, FGM) was applied in 1.5mm increments over etched surfaces and the nylon splint (Mazzafero, Diadema, SP, Brazil) were placed over the unpolymerized resin and then light-cured for 40 s with the same light unit. A final layer of 1.0mm composite resin were applied over the fishing line and re-activated for 40s on each tooth.

Experimental Groups

To conduct the splint removal, the large amounts of composite resin were removed with a high-speed handpiece (KaVo, Biberach, Germany) and a diamond bur (#3083, Angelus Prima Dental, Londrina, PR, Brazil) with conventional light. To remove the 1.0mm remnant composite resin, three lighting methods were used with two different rotatory instruments. The groups are identified as: Va-DB, Va-MLB, Fl-DB, Fl-MLB, CT-DB and CT-MB.

- The Va-DB group, simulated the use of a LED light curing unit (VALO Cordless, Ultradent), in its standard mode with black lens-coupled, associated with a diamond bur #3083 (Angelus Prima Dental);
- Va-MLB group, the VALO LED curing unit was associated with a multifluted 118L bur (Angelus Prima Dental);
- Fl-DB group, the lightning method used was the low-cost violet light spectrum LED clinical flashlight (American Orthodontics, Sheboygan, WI, USA);
- Fl-MLB group was simulated using the flashlight with violet light and the multifluted bur;
- CT-DB group simulated the conventional white light source, with no additional violet lighting associated with a diamond bur (Angelus);
- CT-MB group, the dental trauma splint removal was performed with conventional white light source and a multifluted bur (Angelus);

The experimental design of the study is outlined in Figure 2. The designation of the two rotary instruments was made in the split-mouth model. The lighting method was randomly assigned through a randomization website (www.random.com), generating 5 models with 2 teeth, resulting in n=10 teeth per experimental group.

Scanning and quantitative analysis of enamel surface change

An optical three-dimensional scan was performed (Arti s600 ARTI; Zirkonzahn, Gais, Italy) after application of scanning spray, to digitize all tooth surfaces. The s600 scanner is a fully automated optical stripe light scanner with a large measuring field. All scans were performed by one user according to the manufacturer's instructions The Cumulus software (Regents of the University of Minnesota) was used to align the baseline and post-treatment models by minimizing the root-mean square differences between enamel surfaces (15, 16). The root-mean square values are used to verify deviation between the superimposed models. Thus, a low root-mean square value is related to a high accuracy and precision (17).

The global alignment was initially used between the baseline and post-treatment digital models for the target tooth. The final alignment was done by selecting regions as reference areas that were assumed as identical and not worn (Figure 3). The good alignment of the baseline and post-treatment models were ensured by means of the number of matched points.

The mean and maximum depth values were tested for normal distribution (Shapiro-Wilk) and equality of variances (Levene test), followed by parametric statistical tests. The comparison between the six groups was carried out via two-way ANOVA. Tukey's honest significant difference for post hoc comparisons was used to compare each group to the others. All statistical analyses were performed using Sigma Plot 12.0 (Stata Corp, College Station, TX) and all tests were performed using level of significance of $\alpha=0.05$.

Results

The mean and maximum values for the depth (µm) at the buccal enamel surfaces are shown in Table I. Two-way ANOVA showed significant difference for maximum depth between the groups ($P = 0.015$). Mean and maximum depth defects were significantly smaller in the Va-DB, Va-MLB, Fl-DB, Fl-MLB when compared to the groups that used only conventional light source.

There is a statistically significant interaction between rotatory instrument and lighting ($P = 0.027$). When no additional violet lighting is used, the diamond bur presented higher mean and maximum values for the depth. However, when using additional violet light, the diamond bur and multifluted bur presented similar results. No statistical difference was found between the low-cost violet flashlight and VALO Cordless.

Discussion

The present study showed that the use of different violet light sources and bur types for removing the flexible splints built using composite resin and nylon resulted in different enamel defect depths. Therefore, the hypothesis of this study was rejected.

Different studies showed that the fluorescence-aided identification technique is a good alternative for composite resin remnant removal and a time-saving procedure. (18, 19, 20) However, at the author's knowledge, no study has yet tested the effect of different violet light sources and rotatory instruments. This study presented similar results for the flashlight and the VALO Cordless LED. This finding can be explained due to a similar violet wavelength emitted by these light sources, between 380-420 nm spectrum. The violet light has been widely associated to be helpful for resin removal (21). However, when using fluorescence-aided technique, it is important to follow the safety instructions of the LED manufacturer and to use adequate eye protection such as safety glasses with filter lenses to avoid potentially detrimental health effects of blue-violet and ultraviolet light (22). The flashlight used in this study has a low-cost compared to VALO Cordless LED, and this can be interesting for the general clinician, while the use of VALO Cordless for detecting fluorescent particles in composite resins, requires the acquisition of an accessory lens to be coupled at the VALO, which might not be common in the general clinical offices, increasing the cost. This accessory lens has the purpose to act as a filter from the VALO light curing unit, decreasing the high wavelength to a 405 nm violet spectrum (18, 23). The flashlight can be easily implemented in the daily practice for dental splint removal, bracket debonding cleaning, intraoral examinations and general restorative procedures (24).

The multifluted burs for orthodontic adhesive or composite resin remnant removal is been widely used. (11, 19, 20) The use of this kind of bur has been related to cause less damage to enamel. (9) However, the diamond burs are common on clinical daily practice and its use for residual bonded material removal has already been discussed as a clinical alternative. (25) It is important to emphasize that, for a general clinician treating dental trauma, the tungsten carbide burs might not be available in their offices, leading to the diamond bur use. However, when using diamond bur in high-speed hand-pieces can cause irreversible damages on enamel surface. (9) However, the literature regarding the removal of composite resin using low-speed is unfortunately scarce. The present study showed that diamond and multifluted burs, when associated with additional violet lighting, present similar mean and maximum depths on enamel surface, reaffirming the importance of the fluorescence-aided technique when removing bonded materials that are near to dental structures. Our study also presented lower mean and maximum depths when using multifluted bur compared to other studies, (19, 20) and this might be related to the higher number of blades in the rotary instrument (18-blade multifluted bur), while 6 or 9 bladed burs were used in previous studies. (19, 20)

Recent studies using intra-oral scanners founded smaller enamel defects when using violet light associated with multifluted burs. (19, 20) Although intra-oral scanners are known to be an excellent alternative nowadays, recent studies showed that laboratory scanners have better performance, presenting higher precision when compared to intra-oral scanners, resulting in STL files with minor distortions. (26, 27) This STL file format is native to the stereolithography CAD software created by 3D systems and is important for superposition of the baseline and post-operative files, then lower distortion and more reliable results are expected. The Cumulus software used for the superposition of the STL files in this study is widely used to evaluate tooth surface changes caused by polymerization shrinkage or volume loss, with a recognized precision level. (15, 16)

In this study, the multifluted burs presented good performance even without the additional violet lighting use. That is an important finding, since the violet light source is still uncommon on dental office. Nowadays, even with the fluorescence of different brands and shades of composite resins varying significantly, the majority of the composites (>80%) available should be easily detected when illuminated with fluorescence-inducing diagnostic light of proper wavelength. (27) One well known advantage of the use of violet light is compared with the conventional technique, composite removal with FIT was faster. (23) However, it is important for the clinician that the use of diamond bur mounted in a low-speed contra-angle handpiece associated with an external violet light source is different from the high-speed handpieces with violet light integrated, since there are no low-speed micromotors or handpieces with integrated FIT commercially available (23). These high-speed devices if used with diamond bur, might cause permanent damage to the enamel structure due to his high rotation. (9)

The fluorescence-aided technique performed in this study with two different violet lights and rotatory instruments, showed to be helpful in diminish damage on dental structures. However, the diamond bur in low-speed must be performed with additional violet light. By highlighting the composite resin, the procedure becomes safer and less invasive. The multifluted carbide burs in low-speed presented similar results with and without the violet lights, however, since the composite resin remnant removal is a sensitive procedure and technique dependent, additional light devices can be recommended for both rotatory instruments, decreasing the procedure time, and possible risks of damage to dental structures.

Conclusion

Within the limitations of the study design the following conclusion can be draw: Violet lights used in this study resulted in lower enamel damage when compared to conventional light.

- Both LED light curing unit and the low-cost flashlight presented similar behavior decreasing the enamel damage.
- The diamond bur use at low-speed can result in similar enamel depth as multifluted burs when using with additional violet light. However, its use without additional violet light can be harmful and invasive to the dental structures.

Acknowledgements

The authors thank the support by the National Council of Technological and Scientific Development (CNPq), Coordination for the Improvement of Higher Education Personnel (CAPES) and Foundation of the State of Minas Gerais (FAPEMIG).

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TABLES

Table 1. Mean and maximum depth (µm) of enamel surface after splint removal.

Lighting	**Mean Depth**		**Maximum Depth**	
	Tungsten-carbide burs	Diamond Bur	Tungsten-carbide burs	Diamond Bur
Flashlight	15.8 ± 6.1 Aa	17.7 ± 10.6 Aa	89.2 ± 29.2 Aa	87.9 ± 36.1 Aa
Valo	15.1 ± 7.0 Aa	18.6 ± 14.7 Aa	86.1 ± 44.5 Aa	92.2 ± 29.8 Aa
No light	14.9 ± 8.8 Aa	36.5 ± 17.5 Bb	83.9 ± 34.4 Aa	135.9 ± 32.2 Bb

Different letters mean significant difference ($P<0.05$). Uppercase used for comparing rotatory instrument effect for each lighting type (in columns); lowercase letters used for comparing lighting type for each rotatory instrument (in rows).

FIGURES

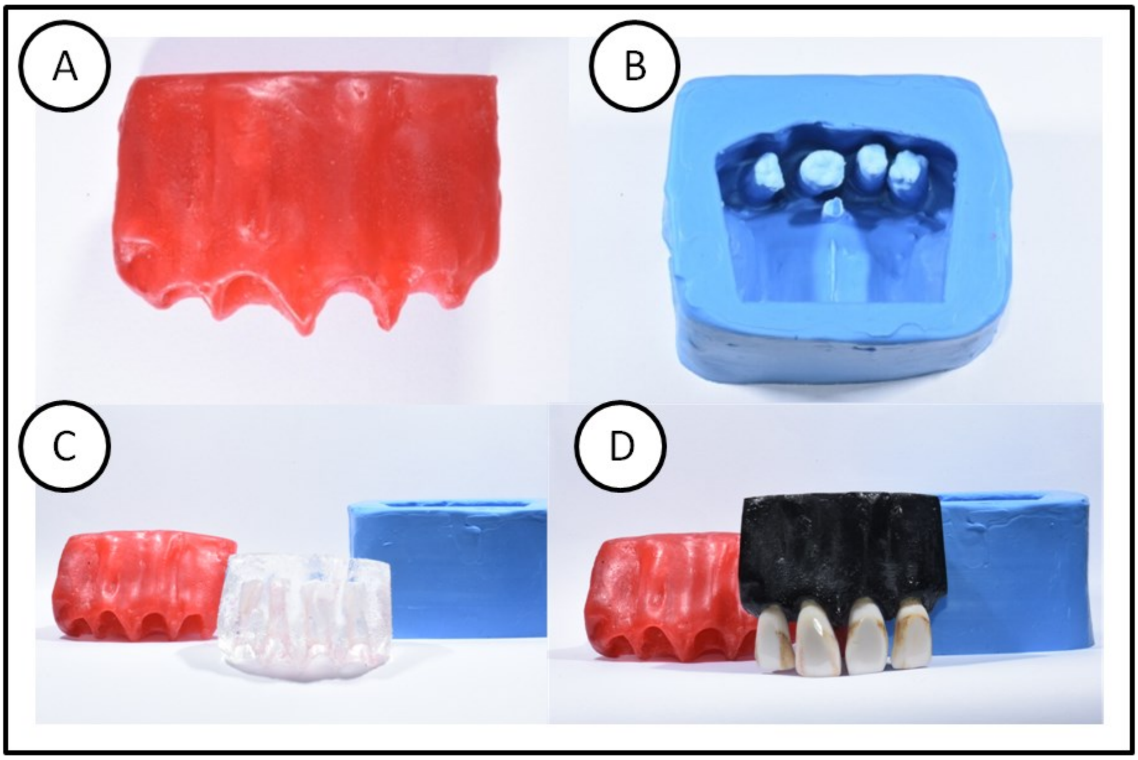

Figure 1. Fabrication of models simulating the clinical condition from teeth 12 to 22. A) Wax modeling of the maxillary structure with four alveoli; B) Impression of the wax model with polyvinylsiloxane material; C) Translucent maxillary replica in polystyrene resin after wax modelling and impression; D) Maxillary model with four teeth and painted in black color for a good scanning process, to avoid the light passing through the maxillary struture.

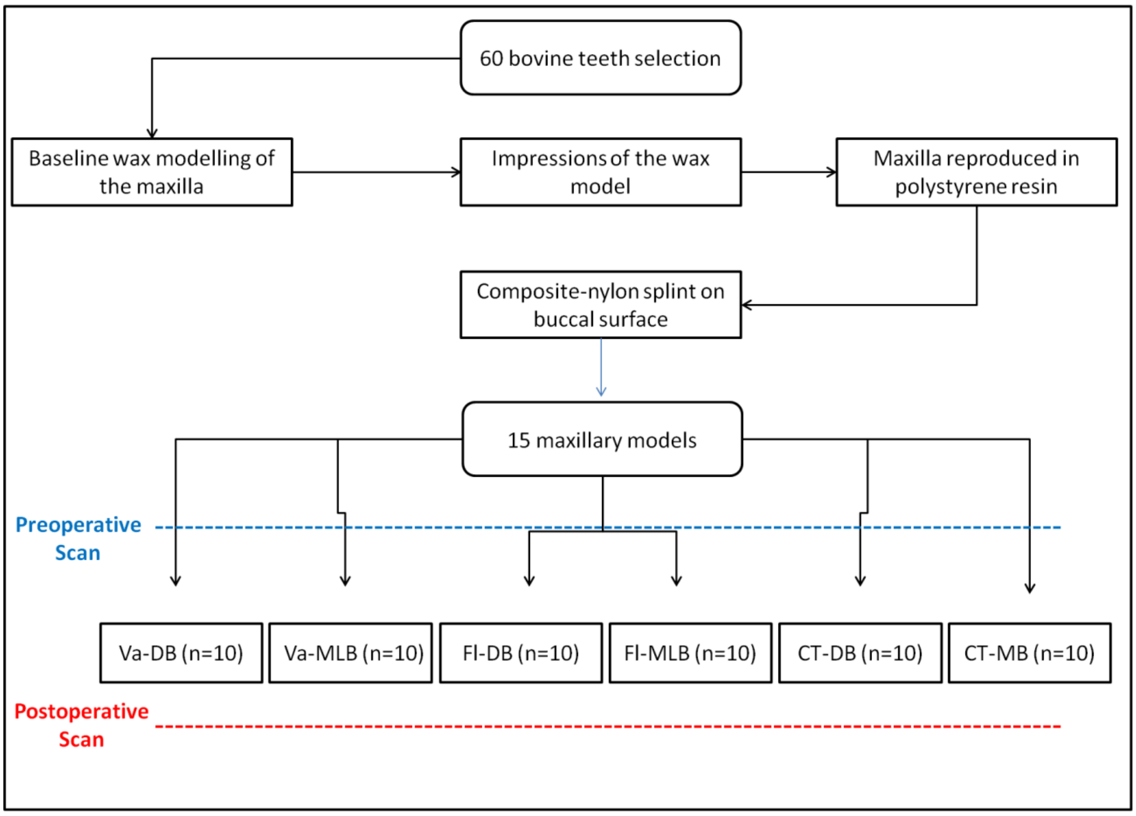

Figure 2. Study flow chart.

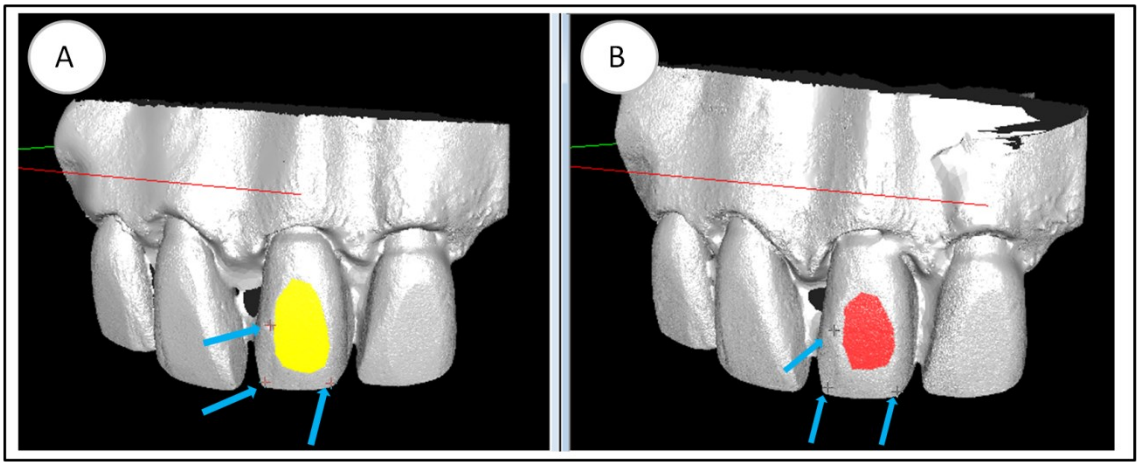

Figure 3. Digitized image of the maxilla replica. The baseline (left) and post-treatment (right) digital models were aligned by using Cumulus software (Regents of the University of Minnesota, Minneapolis). The reference regions are on the buccal surface of the tooth as show in the blue arrows.

CONCLUSÕES

4. CONCLUSÕES

Dentro das limitações metodológicas destes estudos que envolveram três estudos laboratoriais, pode-se concluir que:

1- Os guias para tratamento de lesões de avulsão por traumatismo dentário de dentes permanentes deveriam considerar a contenção de fio de nylon de 1,0 mm e a contenção de fita de soro como materiais flexíveis alternativos para estabilizar dentes avulsionados. Além disso, estender a contenção além dos dois dentes adjacentes não melhora necessariamente a estabilização, embora ainda possa ser uma boa consideração como uma proteção à de falhas adesivas.

2- O fio de nylon de 1,0 mm parece uma boa opção para imobilizar lesões por avulsão durante a dentição mista em comparação com fio de aço de 0.9mm, consideravelmente mais rígido. O fio de nylon fornece flexibilidade, importante para o reparo do PDL, mantendo a estabilidade, mesmo quando na ausência de dentes adjacentes. Extensões além dos dentes diretamente adjacentes não alteraram a mobilidade com o fio de nylon, mas ainda devem ser consideradas uma proteção extra em caso de falha de adesão ou esfoliação dos decíduos.

3-. Durante procedimento de remoção das contenções, tanto o fotopolimerizador LED quanto a lanterna de baixo custo apresentaram comportamento semelhante diminuindo o dano ao esmalte. O uso de ponta diamantada em baixa velocidade pode resultar em profundidade de esmalte semelhante às brocas multilaminadas quando usadas com luz violeta adicional. No entanto, seu uso sem luz violeta adicional pode ser prejudicial e invasivo às estruturas dentais.

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* De acordo com a Norma da FOUFU, baseado nas Normas de Vancouver. Abreviaturas dos periódicos em conformidade com Medline (Pubmed).