SERVIÇO PÚBLICO FEDERAL
MINISTÉRIO DA EDUCAÇÃO
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FACULDADE DE ODONTOLOGIA
PROGRAMA DE PÓS-GRADUAÇÃO

Crisnicaw Veríssimo

Avaliação biomecânica de protetores bucais personalizados: Análise laboratorial e dinâmica não-linear de impacto por Elementos Finitos

Tese apresentada ao Programa de Pós-Graduação em Odontologia da Faculdade de Odontologia da Universidade Federal de Uberlândia, como parte dos requisitos para obtenção do título de Doutor em Odontologia.

Área de concentração: Clínica Odontológica Integrada.

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Prof. Dr. Carlos José Soares - Faculdade de Odontologia - UFU
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Prof. Dr. Alfredo Júlio Fernandes Neto - Faculdade de Odontologia - UFU
Prof. Dr. Saul Martins de Paiva - Universidade Federal de Minas Gerais - UFMG
Prof. Dra. Neide Pena Coto – Universidade de São Paulo - USP

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Ata da defesa de TESE DE DOUTORADO junto ao Programa de Pós-graduação em Odontologia Faculdade de Odontologia da Universidade Federal de Uberlândia.

Defesa de: Tese de Doutorado nº 006 - COPOD
Data: 09/01/2015
Discente: Crisnicaw Veríssimo; Matrícula: (11213ODO004)
Título do Trabalho: Avaliação biomecânica de protetores bucais personalizados: Análise laboratorial e dinâmica não-linear de impacto por Elementos Finitos.
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Linha de pesquisa: Biomecânica aplicada à Odontologia.
Projeto de Pesquisa de vinculação: Biomecânica aplicada à Odontologia.

As **oito** horas e **trinta** minutos do dia **nove de janeiro do ano de 2015** no Anfiteatro Bloco 4L Anexo A, sala 23 Campus Umuarama da Universidade Federal de Uberlândia, reuniu-se a Banca Examinadora, designada pelo Colegiado do Programa de Pós-graduação em fevereiro de 2014, assim composta: Professores Doutores: Alfredo Júlio Fernandes Neto (UFU); Paulo César Freitas Santos Filho (UFU); Neide Pena Coto (USP); Saul Martins de Paiva (UFMG); e Carlos José Soares (UFU) orientador(a) do(a) candidato(a) **Crisnicaw Veríssimo.**

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

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

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

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

Nada mais havendo a tratar foram encerrados os trabalhos às 13 horas e 05 minutos. Foi lavrada a presente ata que após lida e achada conforme foi assinada pela Banca Examinadora.

Profa. Dra. Neide Pena Coto – USP

Prof. Dr. Saul Martins de Paiva – UFMG

Prof. Dr. Alfredo Júlio Fernandes Neto – UFU

Prof. Dr. Paulo César Freitas Santos Filho – UFU

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

DEDICATÓRIA

À DEUS,

“Entregue o seu caminho ao Senhor; confie nele, e o mais ele fará. ”

Obrigado Senhor por sempre iluminar os meus caminhos! Devemos ser a gratos a deus pelos pequenos detalhes da vida e do dia-a-dia. Nestes pequenos detalhes descobrimos o verdadeiro valor das coisas. Obrigado por me dar forças quando pensei que as não teria mais, pelo amparo nos momentos difíceis e por sempre abençoar as minhas escolhas! Agradeço ao senhor por mais esta conquista!

Aos meus pais, **Hudson e Daguimar,**

“Oh, my beautiful mother
She told me, son, in life you're gonna go far
If you do it right, you'll love where you are
Just know, wherever you go
You can always come home
Oh, my irrefutable father
He told me, son, sometimes it may seem dark
But the absence of the light is a necessary part
Just know, you're never alone
You can always come back home

Obrigado Pai e Mãe! Mais uma vez, essa conquista é de vocês! Duas pessoas íntegras e que me deram o bem mais precioso da humanidade: Educação. Obrigado pelo carinho, apoio, dedicação e pelo amor sincero! Obrigado por sempre acreditar em mim! Vocês são e sempre serão meu exemplo de vida. Amo muito vocês dois, muito obrigado.

Ao meu irmão **Saulo,**

Você me ensinou que a melhor coisa da vida é o bom humor! Você é uma das pessoas que mais estimo na minha vida! Sempre que precisar estarei por perto! Obrigado pelos conselhos e pela amizade sincera!! Agradeço pelo carinho que você sempre teve comigo! Te amo!

‘’Mano você é a letra, eu sou a melodia’’.

À minha parceira de vida e amor, **Rebeca,**

O que dizer de você amor; você é uma pessoa maravilhosa e ímpar! Simplesmente não existem adjetivos para expressar o que você é e significa para mim! Muito obrigado pelo seu companheirismo, amizade e amor incondicional. Não tenho e nunca terei palavras para agradecer tudo o que você faz por mim. Tenho a certeza que você merece toda as páginas dessa tese escritas em agradecimento. A cada dia ao seu lado aprendo a te admirar e amar cada vez mais. Obrigado por ter apoiado e participado de todas as decisões que tomei na minha vida profissional. E o mais importante, obrigado por não me deixar desistir dos meus sonhos. Vivemos um período muito difícil alimentado pela distância entre nós. Mas você sempre me deu força e o amparo necessário para continuar em frente. A distância me fez constatar a certeza do nosso amor. Dedico todo este trabalho a você! Hoje você é muito mais que uma namorada, você se tornou a pessoa com a qual quero compartilhar a minha vida eternamente. Te amo, com todas as letras, palavras e pronúncias. Em todas as línguas e sotaques. Em todos os sentidos e jeitos. Em todas as situações e circunstâncias. Simplesmente, te amo!

Ao meu sogro e sogra **Mario e Eliete**,

Agradeço pelas palavras de carinho e pelo apoio que sempre me deram durante a minha caminhada. Vocês são muito especiais pra mim. Que deus sempre os abençõe.

A minha **FAMÍLIA,**

Deixo aqui a minha gratidão a todos os meus familiares avós, tios, tias, primos e primas e em especial aos meus afilhados Isadora e Brunno. Agradeço também a minha cunhada Flávia. Agradeço por cada momento em que me apoiaram e torceram por mim durante esta caminhada.

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De acordo com a Mitologia Grega, Mentor era o filho de Héracles, amigo de Ulisses. Este colocou Mentor para cuidar de seu filho, Telemachus, quando partiu para a Guerra de Tróia. Atenas, então, visitou Telemachus, se disfarçando de Mentor, encorajando Telemachus a se impor contra as pretendentes fornecidas pela sua mãe e viajar para o exterior para descobrir o que aconteceu com seu pai.

Graças a relação de confiança entre Mentor e Telemachus, o nome Mentor foi adotado como um termo significando aquele que compartilha sabedoria e conhecimento com um colega menos experiente.

Carlos, este texto acima trás a origem do significado da relação orientado/orientador. Entretanto com você aprendi o real significado da palavra mentor. Acredito que todos os seus orientados reconhecem o quanto sua orientação foi importante e que ela transcende apenas a transmissão de conhecimento. Seu amor a profissão e capacidade de produzir conhecimento com qualidade e seriedade são exemplos a serem seguidos por qualquer aluno. Serei eternamente grato por todas as oportunidades que me proporcionou. Hoje estou preparado para seguir o meu caminho graças a seus ensinamentos. Muito obrigado! Que Deus sempre ilumine e proteja você e sua familia.

To **Antheunis and Daranee Versluis,**

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See you soon!

Ao amigo e professor **Paulo César de Freitas Santos Filho (PC),** Meu grande amigo e eterno orientador. Chefe, ao olhar para o passado e ver sua preocupação em relação ao meu futuro após o mestrado me sinto profundamente emocionado. Com você aprendi muito mais do que fazer pesquisa! Aprendi como deve ser a postura de um pesquisador e professor universitário. Sua forma de orientar, conduzir seus trabalhos e vida pessoal sempre será inspiração para mim! Obrigado por acreditar em mim e no meu trabalho! Que Deus sempre ilumine seus caminhos e sua família.

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Ao Professor **Adérito Soares da Mota,**

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Conte sempre comigo!

À minha amiga e orientadora **Gabriela Mesquita,**

Gabi, mais uma vez expresso toda minha gratidão a você!! Obrigado pela paciência e orientação durante minha iniciação científica. Acreditar em um aluno de graduação e ensiná-lo em todos os pequenos detalhes de uma pesquisa são caracteristicas de um grande orientador e docente. Nossos momentos de laboratório e de estudos foram muito importantes para meu desenvolvimento profissional. Dedico esta tese em especial a você! Obrigado!!

Aos meus amigos e companheiros, **Rodrigo Jaiba, Luiz Fernando, Alexandre Coelho Machado (Frotinha), João Paulo Servato, Aline e Maiolino,**

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

e à FAPEMIG pelo suprimento das necessidades deste trabalho.

Epígrafe

"In a dark place we find ourselves, and a little more knowledge lights our way."

Master Yoda

SUMÁRIO

LISTA DE ABREVIATURAS E SIGLAS

% - Porcentagem

± - Mais ou menos

µS - Microdeformação

Fig. – Figura

min - minutos

mm - Unidade de comprimento (milímetro)

mm/min - Unidade de velocidade (milímetro por minuto)

mm^2 - Unidade de área (milímetro quadrado)

MPa - força / área (Mega Paschoal)

mW/cm^2- Unidade de densidade de energia (miliwatts por centímetro quadrado)

N - Unidade de pressão - carga aplicada (Newton)

Nº - Número

º - unidade de angulação (grau)

ºC - Unidade de temperatura (graus Celsius)

p - Probabilidade

MTG- Mouthguard

EVA – Etileno Vinil Acetato

α- Nível de confiabilidade

Ω - ohms

ASTM - American Society for Testing materials

RESUMO

Avaliação biomecânica de protetores bucais personalizados: Análise laboratorial e dinâmica não-linear de impacto por Elementos Finitos – CRISNICAW VERÍSSIMO – Tese de Doutorado – Programa de Pós-Graduação em Odontologia – Faculdade de Odontologia – Universidade Federal de Uberlândia

RESUMO

A prática de esportes de contato está altamente relacionada com ocorrência de traumatismos dento-alveolares e protetores bucais têm sido utilizados com objetivo de reduzir os efeitos deletérios destes traumas. O objetivo geral deste estudo foi avaliar a performance biomecânica de protetores bucais personalizados por meio de ensaio experimental de extensometria e análise dinâmica não-linear de impacto por elementos finitos e associar estes achados a aplicação clínica de uso destes dispositivos. Este estudo envolve cinco objetivos específicos. **Objetivo 1:** avaliar a efetividade de uso de modelo experimental dento-alveolar bovino para avaliação do comportamento biomecânico, expresso pelas tensões e deformações geradas pelo uso de protetores bucais bem como validar mutuamente os achados dos ensaios experimentais e da análise dinâmica não-linear de impacto pelo método de elementos finitos. **Objetivo 2** avaliar o efeito de diferentes espessuras (2, 3, 4, 5 e 6mm) de protetores bucais personalizados confeccionados em EVA nas tensões e deformações, capacidade de absorção de impacto e deslocamento do protetor bucal. **Objetivo 3:** avaliar a influência da inserção de material com alto módulo de elasticidade no interior de protetores bucais personalizados confeccionados em EVA no padrão de distribuição de tensões e deformações, capacidade de absorção de impacto e deslocamento do protetor. **Objetivo 4:** avaliar a influência do contato com o dente antagonista no padrão de distribuição de tensões e deformações, capacidade de absorção de impacto e deslocamento de protetores bucais personalizados de EVA. **Objetivo 5:** associar a síntese dos resultados encontrados nos objetivos 1, 2, 3 e 4 associado ao relato de caso clínico de confecção de protetor bucal personalizado em artigo de comunicação aos clínicos brasileiros. Os métodos experimentais utilizados foram extensometria e

teste de impacto, teste de tração para caracterização mecânica do etileno vinil acetato (EVA), e análise dinâmica não-linear de impacto por elementos finitos 2D para avaliação das tensões e deformações geradas pelo impacto. Na análise pelo Método de Elementos Finitos foram utilizados para análise de tensões os critérios de von Mises e von Mises Modificado Crítico. Frente aos resultados concluiu-se que protetores bucais personalizados diminuem os níveis de tensão e deformação no complexo dento-alveolar durante impacto. Na ausência de protetores bucais o impacto horizontal cria condição crítica para fratura dentária na região palatina da coroa dentária. A presença de protetor, reduz de forma significativa a condição crítica de fratura. Empregando testes de impacto com dispositivo pendular em modelo experimental dento-alveolar (bovino) concluiu-se as diferentes angulações (90, 60 ou 45º), objeto de impacto (bola de baseball ou de metal) comprova-se que a presença de protetor bucal reduz significativamente as tensões e deformações frente ao impacto. A velocidade determinada pela angulação de 90º promoveu maiores valores de tensão e deformação. Protetores bucais personalizados demonstraram no teste de extensometria a capacidade de absorção 98% da energia gerada no impacto e 95% na análise de elementos finitos. Os resultados do ensaio de extensometria e do método de elementos finitos, foram validados mutuamente portanto ambas metodologias são consideradas adequadas e complementares para avaliação de protetores bucais. Protetores bucais personalizados devem ser confeccionados na espessura de 3 a 4mm. A inserção de material rígido no interior do protetor bucal (camada média) é recomendada pois reduz os níveis de deslocamento do protetor bucal frente ao impacto sem modificar significativamente os níveis de tensões e deformações. O ajuste do protetor bucal segundo a oclusão do paciente reproduzindo contato com os dentes antagonistas diminui o deslocamento do protetor bucal durante o impacto. Por fim, o clínico deve se ater a todos estes aspectos durante a confecção e orientação de uso de protetores bucais personalizados de EVA visando reduzir os efeitos indesejáveis do impacto em dentes anteriores.

ABSTRACT

ABSTRACT

The practice of contact sports is highly associated with the occurrence of dental injuries. Mouthguards have been widely used in order to reduce the harmful effects of these injuries. The aim of this study was to evaluate the biomechanical performance of custom-fitted mouthguards through strain-gauge test and nonlinear dynamic impact analysis by finite element method. This study was conducted through five specific objectives. **Objective 1:** to evaluate an experimental dentoalveolar model to assess the biomechanical behavior, expressed by the stresses and strains generated by the use of mouthguards and validation of experimental test by means of nonlinear dynamic finite element impact analysis. **Objective 2:** evaluate the stress and strain, shock absorption ability and displacement of EVA custom-fitted mouthguards in different thicknesses (2, 3, 4, 5 and 6 mm). **Objective 3:** To evaluate the influence of hard inserts on the pattern of stress and strain distributions, shock absorption ability and displacement of EVA custom-fitted mouthguards. **Objective 4:** To evaluate the influence of the antagonist contact on the pattern of stress and strain distributions, shock absorbing capacity and displacement of custom mouthguards EVA. **Objective 5:** associate the results found in the objectives 1, 2, 3 and 4 with a clinical case report of custom mouthguard compiled in a communication paper for Brazilian dental clinicians. The experimental methods used were the strain gauge method associated with impact test, tensile test for mechanical characterization of ethylene vinyl acetate (EVA), and nonlinear dynamic impact finite element analysis for evaluation of the stress and strain generated by the impact. In finite element analysis, the von Mises and Critical Modified von Mises criteria were used for stress assessment. Based on the results it was concluded that custom-fitted

mouthguards are capable of reduce the stress and strain levels in the tooth-bone complex during impact. Using Critical Modified von Mises criteria, was found that the horizontal impact and without mouthguards created a critical condition for tooth fracture in the palatal side of the tooth crown. The mouthguard presence decreases significantly this critical condition. In impact tests using the pendulum device and experimental dentoalveolar model (bovine), it was concluded that the different angles (90, 60 or 45º), impact object (baseball or metal ball) and the presence of mouthguard significantly influenced the stresses and strains generated during an impact. The 90° angle promoted higher strain values. Custom-fitted mouthguards have an impact absorption capacity reaching levels of 98% based on the strain gauge test and 95% by finite element analysis. The results of the strain gauge test validated the finite element models, therefore both methods are considered suitable for evaluation of mouthguards. Custom-fitted mouthguards should be made in thickness from 3 to 4mm. The insertion of hard material inside of the mouthguard (middle layer) is recommended because it reduces the mouthguard displacement without significant changes in the stress and strain. The mouthguard adjusted according to the patient's occlusion and antagonist contact decreases the displacement of the mouthguard during an impact. Finally, the clinician must focus on all these aspects during the preparation and orientation of the use of EVA custom-fitted mouthguards.

INTRODUÇÃO E REFERENCIAL TEÓRICO

1. INTRODUÇÃO E REFERÊNCIAL TEÓRICO

A prática de esportes de contato tem aumentado entre crianças e adolescentes apresentando-se como um dos principais fatores causadores de injúrias dento-alveolares (Kujala et al., 1995; Tanaka et al., 1996; Ranalli, 2000; Souza et al., 2011; Farrington et al., 2012). O trauma dento-alveolar pode resultar em diferentes tipos de injúrias envolvendo dentes e tecidos de suporte. Diferentes tipos de luxação e de fraturas dentárias são utilizadas para classificação dos traumatismos dento-alveolares (Lauridsen et al., 2012). A complexidade dos traumatismos dento-alveolares ainda pode ser aumentada pela combinação entre as luxações e fraturas dentárias (Lauridsen et al., 2012). Entretanto, dentre os tipos de traumas, a avulsão dentária, caracterizada pelo completo deslocamento do dente do alvéolo com consequente ruptura do ligamento periodontal, corresponde a 10% dos acidentes que acometem os dentes permanentes e apresentam pior prognóstico de tratamento (Lauridsen et al., 2012). A primeira opção de tratamento nos casos de avulsão é o reimplante imediato, porém a manutenção do dente no alvéolo está relacionada a fatores como tempo para o reimplante, soluções de armazenamento e pela contenção dental realizada após o reimplante (Andreasen et al., 2012; Moura et al., 2014).

Para reduzir os efeitos prejudiciais dos traumas dentários tem sido indicado uso de protetores bucais, que constituem dispositivos utilizados por atletas em especial praticantes de esportes de contato na prevenção de traumatismos dento-alveolares. A primeira tentativa de confecção de um dispositivo para proteção de estruturas orais na prática de esportes foi feita no ano de 1890, quando o dentista inglês Wolf Krause utilizou duas camadas de gutta-percha aderidas aos dentes superiores de um praticante de boxe (Reed, 1994). O objetivo principal do Dr. Krause era proteção dos lábios e dos tecidos moles. No início da década de 1910, foi relatado que um boxeador utilizou dispositivo intra-oral para proteção. Neste segundo relato, o dispositivo foi projetado por um dentista chamado Philip Krause, filho do Dr. W. Krause. Philip Krause não era apenas um dentista, mas também praticante de boxe amador. Ele desenvolveu o chamado "Escudo gengival" utilizando parâmetros que aproximam-se dos dispositivos conhecidos atualmente. Diferentemente de seu pai, Krause utilizou borracha para criar seu protetor bucal (Reed, 1994). Este novo dispositivo não foi amplamente utilizado inicialmente, e houve até resistência à sua utilização em lutas oficiais de boxe. O uso destes protetores tornaram-se prevalentes apartir do ano de 1927 devido a luta de boxe entre Mike McTigue e Jack Sharkey. McTigue claramente vencendo a luta, foi obrigado a desistir do combate devido a fratura dentária e severas lacerações nos lábios. A partir de então, em 1928 a Comissão Atlética do Estado de Nova York foi a primeira nos Estados Unidos a permitir utilização de protetores bucais à pugilistas para preservar a integridade física dos atletas, abrindo possibilidades de uso do protetor bucal para outros esportes (Knapik et al., 2007). Posteriormente, surgem os primeiros relatos na literatura científica odontológica sobre como confeccionar protetores bucais utilizando moldagens, cera e silicone, e até mesmo adição de molas de aço para reforço (Knapik et al., 2007).

O histórico sobre os protetores bucais revela a criação destes dispositivos baseada exclusivamente no empirismo. Com avanço da tecnologia, estudos foram desenvolvidos e postularam que estes aparelhos tem função de distribuir as tensões geradas pelas forças aplicadas diretamente sobre as estruturas faciais e dentárias, e absorver a energia gerada pelo impacto (Ranalli, 2000; Knapik et al., 2007; Farrington et al., 2012). Além dessa função, os protetores atuam de forma a aumentar a distância entre o côndilo e a fossa articular da Articulação temporo-mandibular (ATM) prevenindo o impacto do côndilo com as estruturas adjacentes (fossa articular e base do crânio) diminuindo o risco de concussões cerebrais (Ranalli, 2000; Newsome et al., 2001). Os protetores também tem a função de proteger os tecidos moles de lacerações e escoriações nestas ocasiões de risco.

Atualmente, cinco tipos de materiais tem sido descritos para a confecção de protetores bucais: Copolímero de Etileno e Acetato de Vinila (EVA), cloreto de polivinil, borracha natural, resina acrílica de consistência macia e o poliuretano (Going et al., 1974; Chowdhury et al., 2014). Entretanto, o material usualmente empregado para a confecção dos protetores bucais é o Copolímero de Etileno e Acetato de Vinila ou Etileno Vinil Acetato (EVA) com 18 a 28% de acetato de vinila (Park et al., 1994). O copolímero de etileno e acetato de vinila é formado pelo encadeamento de sequências aleatórias de polietileno e poliacetato de vinila (PVAc). O EVA possui inúmeras aplicações na indústria, especialmente na indústria têxtil e calçadista, sendo utilizado na confecção de placas expandidas para corte posterior de palmilhas e entressolas. Devido a suas propriedades mecânicas, físicas, químicas e biocompatibilidade, esse material é o mais utilizado na confecção de protetores bucais. Dentre estas propriedades, as propriedades elasto-plásticas (histerese) são essenciais para os materiais de confecção de protetores bucais (Low et al., 2002). A histesere é caracterizada pela diferença entre a energia de deformação necessária para gerar determinada tensão no material e a energia elástica nessa tensão (Low et al., 2002). A histerese elástica dividida pela energia de deformação elástica é igual à capacidade de amortecimento do material. Esse comportamento do material, associado ao baixo módulo de elasticidade, reduz a consequência da energia do impacto pela redução das tensões de contato para estrutura bem como pela absorção de parte dessa energia (Low et al., 2002).

Desde o desenvolvimento destes dispositivos, vários aperfeiçoamentos foram realizados para torná-lo mais eficiente. Entretanto, não é necessária licença para fabricação de protetores bucais, não existindo parâmetros de controle de qualidade, sendo assim, diversas variações são encontradas nas propriedades dos protetores produzidos por diferentes fabricantes. Três principais tipos de protetores bucais são normatizados pela American Society for Testing materials (ASTM F697-80): termoplásticos (Boil-and-bite), pré-fabricados (estoque) e personalizados (Sigurdsson, 2013). Atualmente, os protetores bucais personalizados são recomendados pela FDI (Fédération Dentaire Internationale). Os protetores bucais personalizados apresentam vantagens em termos de conforto, adaptação, estabilidade, capacidade fonética e respiratória, além de proporcionar melhor proteção das estruturas dento-alveolares (Duarte-Pereira et al., 2008).

A performance mecânica dos protetores bucais (Capacidade de absorção de choques) pode ser afetada por diversos fatores como: tipo de material, geometria, processo de fabricação e espessura. Todos esses fatores podem também influenciar diretamente na adaptação e conforto de uso. A espessura do protetor parece ser um dos parâmetros mais críticos para a capacidade de absorção de impacto (Westerman et al., 2002; Del Rossi & Leyte-Vidal, 2007). Ademais, a espessura também constitui fator crítico durante a fabricação e pode ser influenciada pela geometria da placa de EVA bem como o processo de aquecimento e moldagem do arco dentário (Mizuhashi et al., 2013; Mizuhashi et al., 2014b; Mizuhashi et al., 2014a). Estudos demonstram que o aumento da capacidade de absorção de choques esta diretamente relacionada com aumento da espessura do material (Westerman et al., 2002; Yamada et al., 2006; Ozawa et al., 2014). Por outro lado, protetores bucais espessos estão relacionados com dificuldades de uso e diminuição da capacidade respiratória e performance dos atletas (Duarte-Pereira et al., 2008). Neste sentido, estudos afirmam que 3 a 4mm representam espessura ideal para promover proteção e conforto durante o uso (Westerman et al., 2002; Duarte-Pereira et al., 2008; Maeda et al., 2008). Outro aspecto que pode representar inovação na confecção destes dispositivos de proteção, com reflexo direto na sua performance biomecânica é a inclusão de camadas intermediárias de materiais com maior rigidez. Pouco tem sido estudado neste horizonte, certamente pela dificuldade de realização em laboratórios e consultórios. Mas esta tecnologia pode ser avaliada no sentido de desenvolvimento de placas de EVA com inserção prévia de laminados confeccionados com materiais de alto módulo de elasticidade. Contudo há de se estudar os efeitos desta estratégia no desempenho mecânico e na estabilidade do protetor em posição quando do impacto.

Os protetores bucais tem sido alvo de diversos estudos que buscam avaliar a capacidade de absorção de choques, entretanto não existem metodologias padronizadas para monitorar a capacidade de absorção de impactos dos protetores bucais. Estudos preliminares definiram que a relação entre as deformações dos protetores e dos dentes é bom indicativo de eficiência destes dispositivos em termos de design e capacidade de absorção de energia (Takeda et al., 2004a; Tiwari et al., 2011). Vários grupos de pesquisa avaliaram a performance mecânica e absorção de impactos de protetores bucais utilizando diferentes tipos de dispositivos para aplicação de impacto baseados no ensaio Charpy ou Izod (Takeda et al., 2004a; Takeda et al., 2004b; Duhaime et al., 2006; Yamada et al., 2006; Takeda et al., 2008; Tiwari et al., 2011; Chowdhury et al., 2014; Ozawa et al., 2014). Dentre eles os mais comuns são os baseados em pêndulos ou impactos diretos, utilizando diversos tipos de objetos como bolas de diferentes materiais ou acessórios esportivos (Takeda et al., 2004c). Estes dispositivos utilizam o princípio da conservação de energia durante movimento pendular orientado pela força da gravidade. Quanto aos sensores de deformação, são utilizados acelerômetros, sensores de fibra óptica (Fiber Bragg gratings sensors - FBGs) e strain gauges, que são considerados como padrão ouro para a obtenção de deformações de estruturas (Takeda et al., 2004a). Os sensores de deformação chamados extensômetros elétricos ou strain gauges são dispositivos de medida que transformam pequenas variações nas dimensões em variações equivalentes em sua resistência elétrica. A medida é realizada por meio da colagem de extensômetro nestas estruturas convertendo a deformação causada na resistência elétrica em quantidade elétrica (voltagem) e amplificando-a para leitura em local remoto: a placa de aquisição de dados (condicionador de sinais).

Embora diversos tipos de testes e desenhos experimentais tenham sido desenvolvidos para o teste de protetores bucais, os mecanismos de absorção de energia permanecem obscuros. Isso se deve principalmente a grande diversidade de modelos experimentais utilizados. Ademais, a maioria destes estudos utilizam modelos monolíticos de resina acrílica para avaliar a performance mecânica (Bemelmanns & Pfeiffer, 2001; Takeda et al., 2004a; Yamada et al., 2006; Tiwari et al., 2011; Bhalla et al., 2013). Entretanto, modelos de resina acrílica não simulam a real condição de tensão/deformação envolvida nos traumas dentários, na medida em que eles não simulam o ligamento periodontal e a movimentação dentária. Em condição fisiológica, os tecidos moles, suporte ósseo, e o ligamento periodontal são importantes estruturas para a distribuição das tensões no complexo dento-alveolar frente a aplicação de impacto.

Outra ferramenta capaz de analisar os campos de tensões e deformações é o Método de Elementos Finitos (MEF). O método de elementos finitos foi desenvolvido na engenharia entre os anos de 1950 e 1960, desde então o método vem sendo extensamente utilizado em diversas áreas do conhecimento. Durante este período o foco principal era a indústria aeroespacial, porém a partir de 1960 surgiram os primeiros softwares comerciais, e após este período, novos softwares foram desenvolvidos. Este método é considerado como sendo o mais compreensível para calcular a complexa condição da distribuição das tensões em diversos materiais, inclusive nos odontológicos, proporcionando dados valiosos com custo operacional relativamente baixo e tempo reduzido (Versluis & Versluis-Tantbirojn, 2011). Na odontologia o potencial do MEF é comprovado em numerosos estudos com análises bidimensionais e tridimensionais.

O Brasil ocupa hoje a 13ª posição entre os países com maior produção intelectual em todas as áreas do conhecimento (Scimago - http://www.scimagojr.com/countryrank.php). Já a Odontologia Brasileira tem se destacado pela crescente produção intelectual de forma quantitativa e qualitativa representando hoje o 2º país mais produtivo na Odontologia Mundial (Scimago). Contudo esta produção intelectual é corretamente direcionada a periódicos de alto impacto que são na sua totalidade publicados em inglês. Como a rotina de leitura de textos em inglês por parte dos profissionais clínicos que atuam exclusivamente nos consultórios ou em serviços públicos não é frequente, este conhecimento se limita a transitar nas esferas acadêmicas. Os eventos científicos nacionais poderiam ser um elo de ligação entre estas duas realidades, porém este têm se tornado cada vez mais foco de divulgação mercantil de produtos sem se ater a divulgação de evidência científica de técnicas, produtos, equipamentos e materiais que podem trazer imediato benefício à prática clínica diária. Revistas nacionais, publicadas na língua portuguesa, de ampla tiragem que cheguem aos consultórios odontológicos devem ser um horizonte para que de forma complementar possamos divulgar os principais achados científicos que estuda-se nos laboratórios e clínicas das Universidades Brasileiras. E ainda há de refletir sobre a necessidade dos egressos dos cursos de pós-graduação brasileira de conseguirem sintetizar seus conhecimentos em uma linguagem direta e acessível aos clínicos e também a sociedade em geral. Ao vincular esta reflexão ao estudo de protetores bucais fica claro o quanto seria impactante para a prevenção de danos causados pelo trauma dental, se os próprios atletas buscassem os consultórios e serviços públicos para a confecção de protetores bucais com princípios biomecânicos adequados. Este é um horizonte que pode ser vislumbrado com a aproximação do conhecimento gerado nas universidades à sociedade em geral por meio dos veículos de comunicação em geral.

Diante deste quadro parece oportuno a análise comparativa de ensaios mecânicos e computacionais que possam nortear a definição de critérios para o desenvolvimento de protores bucais bem como os diversos parâmetros envolvidos na sua utilização, para que estes sejam realmente efetivos na capacidade de absorção de impactos e que este conhecimento gerado chegue tanto aos clínicos bem como a população em geral.

OBJETIVOS

2. OBJETIVOS

Objetivo Geral

Avaliar a perfomance biomecânica de protetores bucais personalizados por meio de ensaios experimentais e análise dinâmica não-linear de impacto por Elementos Finitos.

Objetivos específicos

Objetivos específico 1

Capítulo 1 - *Evaluation of a dentoalveolar model for testing mouthguards: Stress and strain analyses.*

Este objetivo específico avaliou o uso de modelo experimental dento-alveolar para avaliação do comportamento biomecânico de protetores bucais, expresso pelas tensões e deformações geradas bem como validação mútua de ensaio experimental e análise dinâmica não-linear de impacto por Elementos Finitos.

Objetivos específico 2

Capítulo 2 - *Custom-Fitted EVA Mouthguards: What is the ideal thickness? A dynamic finite element impact study*

Este objetivo específico avaliou as tensões e deformações, a capacidade de absorção de impacto e o deslocamento de protetores bucais personalizados construídos em EVA variando a sua espessura (2, 3, 4, 5 e 6mm).

Objetivos específico 3

Capítulo 3 - *Modifying the biomechanical response of mouthguards with hard inserts: a finite element study*

Este objetivo específico avaliou a influência da inserção de material com alto módulo de elasticidade em diferentes desings aplicados à protetores bucais personalizados de EVA no padrão de distribuição de tensões e deformações, capacidade de absorção de impacto e deslocamento.

Objetivos específico 4

Capítulo 4 - *Can the antagonist tooth contact influence the biomechanical response of mouthguards during an impact?*

Este objetivo específico avaliou a influência do contato com o dente antagonista estabelecido em protetores bucais personalizados de EVA no padrão de distribuição de tensões e deformações, capacidade de absorção de impacto e deslocamento.

Objetivos específico 5

Capítulo 5 - Protetores bucais personalizados: aspectos clínicos e biomecânicos.

O objetivo deste capítulo foi gerar síntese dos resultados encontrados nos objetivos 1, 2, 3 e 4 associado à relato de caso clínico compilados em um artigo de comunicação aos clínicos brasileiros cumprindo a função social da geração de conhecimento.

CAPÍTULOS

3.1 CAPÍTULO 1

Evaluation of a dentoalveolar model for testing mouthguards: Stress and strain analyses.

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Title: Evaluation of a dentoalveolar model for testing mouthguards: Stress and strain analyses.

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Abstract

Custom-fitted mouthguards are devices used to decrease the likelihood of dental trauma. The aim of this in vitro study was to develop an experimental bovine dentoalveolar model with periodontal ligament to evaluate the mouthguard shock absorption, the strain and stress behavior due to impact force. It was developed a pendulum impact device to perform the impact tests with two different impact materials (Steel ball and baseball). Five bovine jaws were selected with standard age and dimensions. 6mm EVA mouthguards were made for the impact tests. The jaws were fixed on the pendulum device and the impacts were performed with 90, 60 and 45º, with and without the mouthguard. Strain-gauges were attached at palatal surface of the tooth that the impact was performed. The strain and shock absorption of the mouthguards was calculated and data was analyzed with 3-ANOVA and Tukey Test ($\alpha=0.05$). 2D finite element models were created based on the cross-section of the bovine dentoalveolar model used in the experimental test. A non-linear dynamic impact analysis was performed and the strain and stress distributions were evaluated. Without mouthguards, the increase in impact angulation increases significantly the strain and stress. The use of mouthguards is related to lower strain and stress values. It was concluded that the impact velocity, impact object (steel or baseball ball) and the mouthguard presence affected the impact stresses and strains in a bovine dentoalveolar model. Experimental strain measurements validated the finite element models; therefore both methodologies are suitable for evaluating the biomechanical performance of mouthguards.

Keywords: Mouthguard; Mathematical modeling; Impact absorption ability; Stress; Strain-gauge

1. Introduction

Sport activities frequently lead to dental trauma injuries (Lauridsen et al., 2012; Tuna and Ozel, 2014). During an athletic season, there is 1 in 10 risk of dental or facial injuries (Takeda et al., 2008). With the popularization of some extreme and contact sports, the occurrence of dental traumas is very common for children and young adults (Sigurdsson, 2013). Sports such as rugby, football, American football, hockey, cricket and martial arts are considered to be sports with high incidence of orofacial injuries, whereas basketball, cycling, horse riding, gymnastics and squash are considered to be medium risk (Farrington et al., 2012). Dental trauma injuries can occur in many different ways, involving crown or root fracture, extrusion, subluxation, and avulsion. (Andreasen et al., 2012; Andreasen and Ravn, 1971; Diangelis et al., 2012; Flores et al., 2001).

Mouthguards have been used for preventing dental trauma and oral injuries (el Rossi and Leyte-Vidal, 2007; Labella et al., 2002; Low, 2002; Patrick et al., 2005). The primary function of this device is to prevent violent direct contact with the tooth and between the upper and lower dentition (Cummins and Spears, 2002; Miura et al., 2007; Patrick et al., 2005; Poisson et al., 2009). Stock prefabricated mouth-formed (boil-and-bite) and custom-fitted mouthguards are the most common types available. Some studies reported that custom-fitted mouthguards have superior performance, providing better fit and comfort (Duarte-Pereira et al., 2008). Mouthguard thicknesses ranging from 2 to 6 millimeters were reported in literature. Recent studies showed that 3 or 4 millimeters thickness provide efficient protection and comfort (Ozawa et al., 2014; Westerman et al., 2002; Yamada et al., 2006). Even though many types and thicknesses are available, there is still a lack of understanding about the mechanism of impact absorption and stress distribution of mouthguards, which may be due to the diverse experimental models used to test the parameters involved in dental trauma. Some studies have used solid acrylic resin models (Typodonts) to evaluate mouthguard performance (Bemelmanns and Pfeiffer, 2001; Bhalla et al., 2013; Takeda et al., 2004a; Tiwari et al., 2011; Yamada et al., 2006). However, acrylic resin models cannot simulate the periodontal ligament (PDL) and tooth displacement. Under physiological condition, the soft tissue, supporting bone and periodontal ligament play a crucial role in the mechanisms of stress distribution over the bone-tooth complex during impact (Coto et al., 2012). Accurate simulation of the periodontal ligament in computational and in vitro studies has been shown to directly influence the results of strain, stress, and fracture resistance (Soares et al., 2005).

In reality, dental and facial traumas occurring during sport events can be divided into three groups: impact between players, impact with the ground, and impact with the objects used in the sport (Tanaka et al., 1996). These different categories can generate different impact energies on the athlete. Experimental studies have simulated these impact energies by varying the impact angles, velocities, and materials (Tiwari et al., 2011).

The purpose of this in vitro study was to develop an experimental bovine dentoalveolar model with periodontal ligament to evaluate the mouthguard shock absorption, the strain and stress behavior due to impact force, and additionally to validate the models by means of a dynamic finite element impact analysis (FEA). The null hypothesis tested was that the strains and stresses generated by the impact would not be affected by the impact velocity, impact object (steel or baseball ball) or presence of a mouthguard (with or without).

2. Materials and Methods

2.1. Impact test of bovine dentoalveolar model.

A pendulum device was constructed similar to the conventional Charpy Impact Test (Figure 1A). The pendulum device has interchangeable impact objects and different impact velocities (pendulum drop from 45, 60 or 90º angles) (Figure 1B). Two impact objects were used: a stainless steel ball and a baseball ball (Figure 1C and 1D, respectively). Ten bovine jaws were selected from animals with similar ages (3 to 4 years old) and sizes by measuring the buccolingual and mesiodistal widths of the two central incisors, allowing a maximum deviation of 10% from the average to standardize the dimensions. The jaws were sectioned to exclude posterior teeth, leaving the anterior region and a 10 cm segment of the jaw. After that, the jaws were cleaned with a scalpel blade removing all soft tissue except around the teeth. After cleaning, the jaws were stored in distilled water. The samples were divided into two groups (n=5) according the impact object type (210 g steel ball or 147 g baseball) and tested within 24 hours.

Impressions of the jaws were made with polyvinylsiloxane impression material (Express XT, 3M ESPE, St. Paul, MN, USA) and poured with Type IV stone (Durone IV; Dentsply, Ballaigues, Switzerland) for custom-fitted mouthguard fabrication. A 6-mm thick EVA (ethylene vinyl acetate) custom-fitted mouthguard was made (Bio-art EVA sheets, São Carlos, SP, Brazil) by molding each individual plaster model in a vacuum-forming machine with the EVA plate (Plastivac P7; Bio-art). The 6-mm thickness was chosen for the mouthguards because of the large dimensions of bovine teeth compared with human teeth. The jaw samples were fixed in the pendulum device by two screws located at mandibular canal to prevent jaw displacement during the impact test. Each sample, with and without mouthguards, received three impact velocities with the pendulum dropping from three different angles (45, 60 and 90º). A steel ball or baseball ball was used as the pendulum, i.e., 'impact object'. One unidirectional strain gauge PA-06-060BG-350LEN (Excel Sensors, São Paulo, SP, Brazil) with an internal electrical resistance of 350 Ω, a grid size of 4.2 mm^2 and a gage factor of 2.13 was attached to the palatal surface of a bovine right central incisor using cyanoacrylate resin adhesive (Super Bonder, Loctite, SP, Brazil). The strain gauge was oriented parallel to the tooth long-axis. The impact was targeted at the center of the tooth at the level where the strain gauge was bonded. The strain gauge was connected to a data acquisition device through a half-bridge Wheatstone circuit (ADS0500IP; Lynx, São Paulo, SP, Brazil). Additionally, a control specimen with a strain gauge but not subject to impact was used for environmental temperature compensation. Due to the short period of the impact test, data was acquired at 500 Hz and recorded using signal transformation and data analysis software (AQDADOS 7.02 and AQANALISYS; Lynx). The strain values were statistically analyzed by 3-way analysis of variance (ANOVA) and the Tukey Honestly Significant Difference (HSD) test (α=.05). Shock absorption (%) achieved with the mouthguards was calculated from the peak strain values.

2.2. Finite element analysis (FEA)

2.2.1. Elastic modulus (E) assessment of ethylene vinyl acetate (EVA)

Six EVA specimens, 70x10x3 mm, were secured between two pneumatic clamps (2712 Series Pneumatic Action Grips, Instron Corporation, Norwood, MA, USA) in a universal testing machine (Instron 5500 Series, Instron Corporation). A nondestructive tensile load from 0 to 150 N at crosshead speed of 500 mm/min was applied while load and displacement were recorded (BlueHill 2 software, Instron Corporation). Stress-strain curves were calculated and plotted for each sample. The strain (ε) was calculated from the ratio between the displacement and the initial length between the clamps, and the stress (σ) from the ratio between the load and the specimen cross-section area for each data plot. The elastic modulus (E) was calculated from the middle portion of each stress-strain curve (avoiding the initial alignment slack of the clamps): $E = (\sum \Delta\sigma/\Delta\varepsilon)/N$, where $\Delta\sigma$ is a stress increment and $\Delta\varepsilon$ is a strain increment, and N is the number of data points.

2.2.2. Elastic modulus (E) assessment of bovine enamel and dentin

Five bovine enamel and dentin specimens were embedded in methacrylate resin (Instrumental Instrumentos de medição Ltda, São Paulo, SP, Brazil). Prior to testing, the surfaces were finished with metallografic diamond pastes (6-,3-,1-, and ¼-μm sizes; Arotec, São Paulo, SP, Brazil). Using a dynamic microhardness indenter (CSM microhardness Tester, CSM instruments, Peseux, Switzerland), seven nanoindentations were made every 0.08 mm. The indentations were carried out with controlled force, whereby the test load was increased or decreased at a constant rate between 0 and

500 mN in 15 second intervals, with a maximum load of 500 mN held for five seconds. The load and penetration depth of the indenter were continuously measured during the load-unload cycles. Universal hardness was defined as the applied force divided by the apparent area of the indentation at the maximum force and expressed in Vickers Hardness (VH) units by applying the conversion factor supplied by the manufacturer. The indentation modulus was calculated from the tangent of the indentation depth curve at maximum force, which is comparable to the E of the material.

2.2.3. Dynamic finite element impact analysis

The two impact objects (steel ball and baseball) were modeled in the finite element analysis. Mechanical properties of the stainless steel ball were taken from the literature (ASTM-International, 2013), whereas the load-displacement response of the baseball ball was experimentally obtained. The American Major League baseball ball (Rawlings Company, St. Louis, MO, USA) had a cork sphere in the center, surrounded by a two layers of rubber. Surrounding this inner core were several layers of tightly wound yarn, covered by a thin layer of tweed, and finally a leather outer cover. The baseball ball was subjected to a nondestructive compression load from 0 to 1000 N between two flat steel tables (Figure 2A) at a crosshead speed of 100 mm/min, while the load and displacement were recorded. A two-dimensional (2D) model of the baseball was created in a finite element analysis software (Figure 2B) (Marc/Mentat, MSC software, Santa Ana, CA, USA). Using contact analysis, the loading conditions of the experimental test were simulated. The elastic modulus properties were adjusted until the load displacement was the same as observed in the experimental test at 1000

N. The load-displacement curves for the experimental test and finite element analysis are shown in Figure 2. The elastic modulus for the baseball was determined as 1200 MPa.

Two 2D finite element models were created based on a digital photograph of the cross-section of the bovine dentoalveolar model used in the experimental impact test (Figure 3A). The outlines of the bovine models were traced (Figure 3B) (Image J software, public domain, Java-based image processing and analysis software developed at the National Institute of Health, Bethesda, MD, USA) and x-y-coordinates were imported in the finite element analysis software (Marc/Mentat). An element mesh was manually created using four-node isoparametric arbitrary quadrilateral plane strain elements with reduced integration (one integration point; MARC element type 115) (Figure 3C). Frictionless contact was assumed between the mouthguard and bovine tissues (Figure 3D); node separation between them was allowed during the impact. All other interfaces were continuous and inseparable. The impact objects were also modeled, featuring the same dimensions as in the experimental test. A non-linear dynamic impact analysis was performed using the Single Step Houbolt method. This algorithm is recommended for implicit dynamic contact analyses (Chung and Hulbert, 1994). The final velocity for each pendulum drop angle (90, 60 and 45º) was calculated using the principle of conservation of energy, in which all the potential energy (Ep = m g h'; where m is mass, g is acceleration due to gravity, h' is pendulum height) was transformed into kinetic energy (Ek = 0.5 m v^2; where v is velocity) on the impact (Ep = Ek). For a pendulum length h and angle θ, the height h' was h'= h (1 – cos θ), thus the velocity v at impact $v = \sqrt{2.gh(1 - cos\phi)}$, where g is the acceleration due to gravity.

The calculated impact velocities for pendulum length h = 0.5 m and g = 9.81 m/s^2 were 3.13, 2.21, and 1.71 m/s for the 90, 60 and 45º pendulum drop angles, respectively. These values were applied as the initial velocities for the impact objects in the x-direction (horizontal in Figure 3), while no displacement was allowed in y-direction (vertical) to simulate the rigid pendulum lever. Nodes at the bottom of the bone structure were rigidly fixed in x- and y-directions, simulating the experimental condition. The impact time period was chosen to allow the impact objects to bounce back to their original position. All materials were considered linear, isotropic and homogeneous. The applied mechanical properties (elastic modulus, Poisson's ratio and material density) are shown in the Table 1. A custom subroutine recorded the strain values in the y-direction for one node placed where the unidirectional strain gauges were attached in the experimental tests. The stress distributions were analyzed using von Mises equivalent stresses at the maximum peak of the impact. The von Mises criterion was not chosen to reflect failure behavior (it does not take the difference between tensile and compressive strengths into account), but rather as an expression the energy of the impact stresses. Based on the peak strain values, the shock absorption capability (%) was calculated for the models with mouthguards as the percent of peak strain without mouthguard.

3. Results

3.1. Experimental test – Strain gauge measurement

The mean and standard deviation [SD] for the impact strain (µS) with baseball ball or steel ball are shown in Table 2. The 3-way ANOVA indicated that the factors:

pendulum drop angle (and thus impact velocity), mouthguard presence, object of impact and their interaction were all significant ($P<.001$). Mouthguards significantly reduced the strain, regardless of the impact velocities of the impact objects. With mouthguard, the impact velocities did not influence the strains for the steel ball and baseball. For the steel ball, without mouthguard, the strain was significantly higher at the highest impact velocities (90 and 60º) compared to the lowest velocity (45º). There was no difference in strains between the pendulum drops from 90 and 60º. For the baseball, there were no significant differences in strain between the three different impact object velocities. Without mouthguard, the steel ball caused higher strain values than the baseball.

3.2. Elastic modulus assessment of polyvinyl acetate-polyethylene copolymer (EVA)

The elastic behavior of the EVA material is shown in the stress-strain curves in Figure 4. The mean [SD] for the EVA elastic modulus was 18.075 [0.457] MPa. This value was used in the finite element analysis.

3.3. *Elastic modulus (E) assessment of bovine enamel and dentin*

The mean [SD] for the bovine enamel and dentin elastic modulus values were 87070 [3540] and 17580 [450] MPa, respectively. These values were used in the finite element analysis.

3.4. Finite element impact analysis

The von Mises stress distributions at the peak of the impact of the steel ball and baseball without mouthguard are shown in Figure 5. The distributions for the cases with mouthguard are shown in Figure 6. Without mouthguard, stress concentrated at the enamel where the impact was applied, irrespective of impact object. The stress values generated by the steel ball were higher than by the baseball ball. Decreasing the impact velocity (i.e., pendulum angle) resulted in a reduction in stress values. The highest stresses were found for the model without mouthguard impacted by a steel ball released from the 90º angle (Figure 5A). With mouthguard, at the peak of the impact, the stresses concentrated in the root dentin structure (Figure 6). The microstrain values calculated during the impact are shown in Figure 7 and Table 3. Without mouthguard, the strain values generated by steel ball were higher than baseball ball at each velocity. With mouthguard, a small difference was found in the strain values between the baseball and steel ball. The strain values also showed that time to reach the strain peak was higher than with the mouthguard, regardless of the impact object. Without mouthguard, the impact time to reach the strain peak was higher for the baseball than for the steel ball.

3.5. Shock absorption in experimental test and finite element analysis

The shock absorption ability is shown in Table 4. For the experimental strain gauge measurements, the highest values of shock absorption were found for the impact made at the highest velocity (90º) and steel ball (98.2%). The shock absorption with the impact object released from 45º was the lowest value, regardless of impact object. Impacts made with the baseball ball showed lower shock absorption values than with the steel ball. In the finite element analysis the shock absorption with the steel ball was substantially higher than with the baseball ball, with only small differences between the different velocities for both impact objects.

4. Discussion

The null hypothesis was rejected. Impact velocity, mouthguard presence and impact object had significant effect on the stresses and strains in bovine anterior teeth. In dentistry, destructive mechanical tests used to determine fracture resistance are important means of analyzing the biomechanical behavior of teeth (Veríssimo et al., 2013). However, they have limitations in obtaining information about the internal behavior of the tested models. Therefore, it is important to use nondestructive methodologies, such as strain gauge measurements and finite element analysis. Experimentally, accelerometers and fiber optic sensors (Fiber Bragg gratings sensors - FBGs) have also been used, but strain gauge is the most common method for measuring the effect of impact loads (Takeda et al., 2004a; Tiwari et al., 2011). Using high frequency data acquisition, strain gauges are able to collect data for short events like an impact load, and have been preferred for testing the biomechanical response of mouthguards (Takeda et al., 2004a).

Finite element analysis was developed as an engineering tool to solve stress and strain conditions in complex structures. Most studies evaluated the stress distributions with or without mouthguards using linear-static load applications (Bemelmanns and Pfeiffer, 2001; Miura et al., 2007; Tiwari et al., 2011). This study used a non-linear dynamic finite element impact analysis to evaluate the stress and strain distributions assuming plane strain conditions in the structures' cross-sections. Dynamic and the static analyses differ mainly in the load application. If a load is applied sufficiently slowly, inertia forces can be ignored and the analysis can be simplified as a quasi-static analysis. However, such quasi-static conditions cannot be expected during the impact of an object with a mouthguard, and therefore inertia and acceleration should be included in the stress analysis of impacted structures. Interface conditions are important for the stress analysis. Most of the FEA analyses in dentistry are performed with perfect bonded interface, which means that the elements at the interfaces are sharing the same node. In reality, mouthguards are not bonded to the tooth surface and interfacial interactions (contact, sliding, separation) can be critical (Srirekha and Bashetty, 2010). In this study non-linear contact analysis between the mouthguard and the bovine model was used to evaluate the contact status during the impact. The assumption of plane strain conditions in the cross-section allowed a two-dimensional model, which has the advantage of reduced operational computer cost and time. To increase the stiffness and be more comparable with a 3D tooth structure, the pulp cavity was filled with elements with the properties of dentin. To ensure that the geometric simplifications were justified we validated the FEA results by comparing the calculated strains with the strain gauge measurements. This comparison confirmed similar behavior between the FEA and experiments for the conditions tested (Table 2 and 3).

This study developed and evaluated an experimental model to test the strain, stress and shock absorption ability (defined as the reduction in peak strains) of mouthguards. Several studies have tested shock absorption ability and the strain generated by different impact tests (Andersson et al., 2012; Bemelmanns and Pfeiffer, 2001; Fresvig et al., 2008; Ozawa et al., 2014; Takeda et al., 2004a; Takeda et al., 2004b). However, these studies used acrylic resin as experimental models (typodont), which are monolithic and do not reproduce enamel, dentin, periodontal ligament (PDL) and bone support. Consequently, they cannot simulate the physiological stress and strain behavior in teeth during impact loading. Moreover, PDL has a complex viscoelastic behavior that could significantly influence the response to impacts. Some studies have tried to create and reproduce the behavior using soft materials to simulate the interaction between tooth and bone socket (Soares et al., 2005). This study used an ex-vivo bovine model that combined the presence of a PDL with the natural anisotropic structures of enamel, dentin and the bone complex.

Many studies have suggested that mouthguard use prevents tooth or maxillofacial trauma (Takeda et al., 2004b). However, the values of shock reduction ability reported by those range between 10-80%. This range may reflect the different mouthguard model types and impact devices (pendulum, drop ball, universal testing machine for tension/compression). The results of the present study showed that the response of mouthguards reported in the literature might be underestimated since we found shock absorption ability at levels of 98% for the strain gauge measurement and 95% for the dynamic finite element impact analysis.

The results from the strain gauge measurements showed that the use of mouthguards is associated with lower strain values, regardless of the impact velocity and the type of impact object. The same behavior was observed in the dynamic finite element analysis, which also showed that the presence of a mouthguard changes the location of the stress concentrations at the peak of impact. For both types of impact objects, the stresses were concentrated in the tooth crown for the models without mouthguard. On the other hand, the highest stresses were in the root for the models with mouthguard. We also observed that the mouthguard increased the time to reach the peak of impact. The high compliance of the EVA absorbed much of the impact energy, decreasing the stress and strain values in the tooth structure. The increased time afforded by the deformation of the mouthguard allowed better distribution of impact force through the PDL and bone. This energy absorption mechanism corroborates the importance of using mouthguards in sports to reduce the risk of dental traumas (Bemelmanns and Pfeiffer, 2001; Kujala et al., 1995; Labella et al., 2002; Woodmansey, 1997).

In general, studies reported that the use of rigid impact materials caused higher strain values in the tooth than softer materials (Park et al., 1994; Takeda et al., 2004b). The results of this study also found that the rigid steel ball caused higher stress and strain values than a softer object like baseball ball (Figures 5-7), especially at the highest impact velocity (pendulum drop from 90º). Although the velocity of both objects was the same at impact, the high density of the steel ball (thus higher mass and consequently higher kinetic energy and inertia) in combination with the high elastic modulus, i.e., less deformation, meant that more of the impact energy transferred to the target, creating higher stresses and strains. This behavior was also observed in the finite element analysis. On the other hand, the softer baseball ball produced lower levels of strain and stress than the steel ball. Other studies reported similar results (Takeda et al., 2004a; Takeda et al., 2004b). Softer objects that are easier to deform absorb more energy at the moment of the impact. This response was also observed in the finite element analysis as a longer impact time for the baseball ball.

The strain gauge analysis and FEA results showed similar general behavior for the factors under study. Therefore, the experimental bovine dentoalveolar model with strain gauges and the 2D dynamic finite element impact analysis were suitable for the analysis of the biomechanical behavior of mouthguards. Future studies involving 3D finite element model of human dentoalveolar structure could further improve the accuracy of the impact analyses. The findings of the present investigation strongly support that EVA mouthguards are able to reduce the stresses and strains caused by an impact and thus these devices are likely to prevent oral and facial traumas.

5. Conclusion

Within the limitations of this study the following conclusions can be drawn:

- The impact velocity, impact object (steel or baseball ball) and the presence of a mouthguard significantly affected the impact stresses and strains in a bovine dentoalveolar model.
- The highest impact velocity caused the highest stress and strain values for the steel and baseball balls. The steel ball resulted in higher stress and strain values than the baseball ball regardless of the mouthguard.
- The custom-fitted mouthguard had a shock absorption ability reaching 98% based on strain measurements and 95% in the finite element impact analysis.
- Results from the experimental strain measurements validated the finite element models; therefore both methodologies are suitable for evaluating the mechanical performance of mouthguards.

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Declaration of Interests: The authors certify that they have no commercial or associative interest that represents a conflict of interest in connection with the manuscript.

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Tables

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

Material	Elastic Modulus (MPa)	Poisson's ratio	Density (g/cm^3)
Bovine Enamel	87070	0.3	2.14
Bovine Dentin	17580	0.3	2.97
EVA	18.075	0.3	0.94
Soft tissue	1.8 (Holberg et al., 2005)	0.3	0.95
Compact bone	11600 (Van Buskirk et al., 1981)	0.3	2.0
Trabecular bone	800 (Guillen et al., 2011)	0.3	0.7
Periodontal ligament	50 (Rees and Jacobsen, 1997)	0.45	0.95
Steel	200000 (ASTM-A276)	0.3	7.8

Table 2- Mean peak strains [standard deviation] (µS) and the results of the Tukey honestly significant difference test for the strain gauge measurements*.

Pendulum drop angle	Steel ball		Baseball Ball	
	Without mouthguard	With mouthguard	Without mouthguard	With mouthguard
90°	2562.6 [926.5] A, a, £	45.2 [16.4] B, a, £	101.7 [20.9] A, a, €	26.7 [10.8] B, a, £
60°	1546.4 [304.8] A, a, £	40.9 [13.4] B, a, £	73.5 [19.4] A, a, €	23.7 [8.1] B, a, £
45°	101.8 [37.8] A, b, £	37.6 [10.9] B, a, £	59.9 [20.8] A, a, €	21.5 [5.4] B, a, £

*Different letters indicate significant differences for Tukey honestly significant difference test (P<.05). Uppercase letters compare mouthguard presence factor in each impact device (in rows). Lowercase letters compare pendulum drop angle factor (in columns). Symbols compare impact object factor in each mouthguard usage condition (in rows).

Table 3- Maximum peak strain values (µS) determined with the finite element analysis.

pendulum drop angle	Steel ball		Baseball Ball	
	Without mouthguard	Without mouthguard	Without mouthguard	With Mouthguard
90°	420.51	78.82	78.82	19.74
60°	287.11	50.61	50.61	13.57
45°	184.41	28.90	28.90	9.73

Table 4- Mouthguard shock absorption (%) determined from the strain gauge measurements and the finite element analysis.

pendulum drop angle	Strain gauge measurements		Finite element analysis	
	Baseball Ball	Steel ball	Baseball Ball	Steel ball
90^o	73.7%	98.2%	80.41%	95.30%
60^o	68.0%	97.3%	78.64%	95.27%
45^o	64.1%	63.0%	68.96%	94.72%

Figures

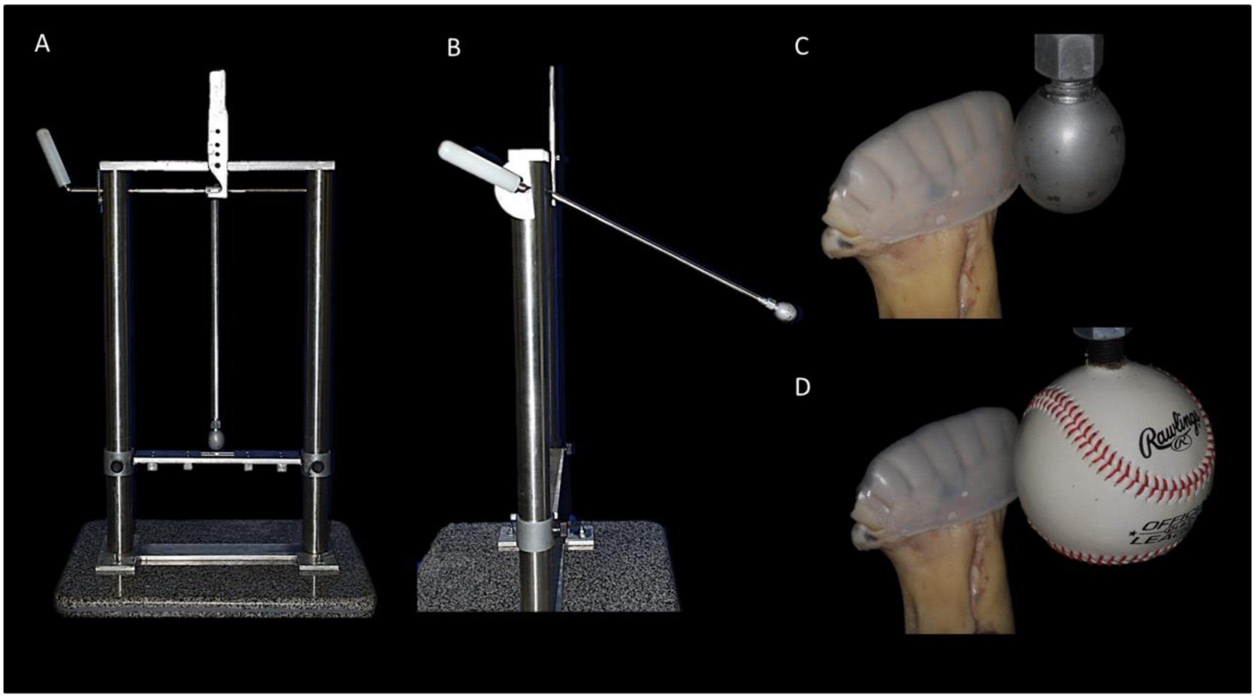

Figure 1. A) Front view of pendulum impact device; B) Side view of pendulum impact device; C) steel ball (210g), and D) Baseball (147g) on bovine dentoalveolar model.

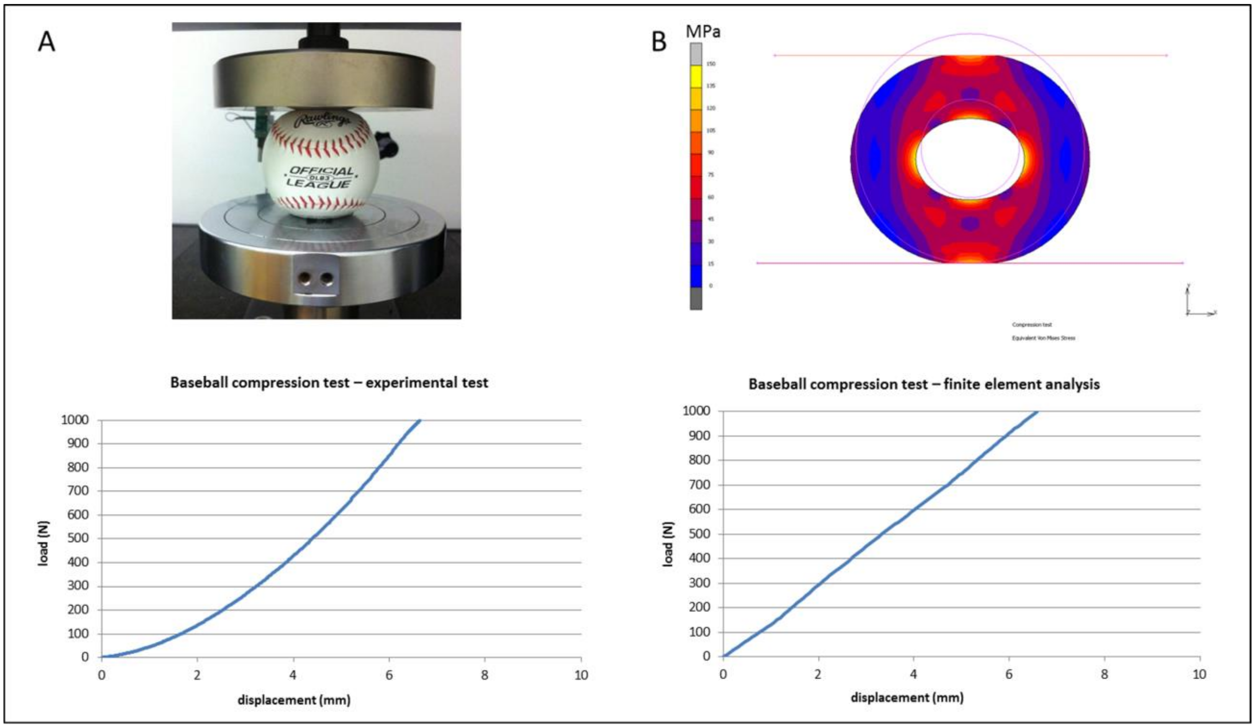

Figure 2- Baseball compression test. A) Experimental set-up; B) Finite element simulation.

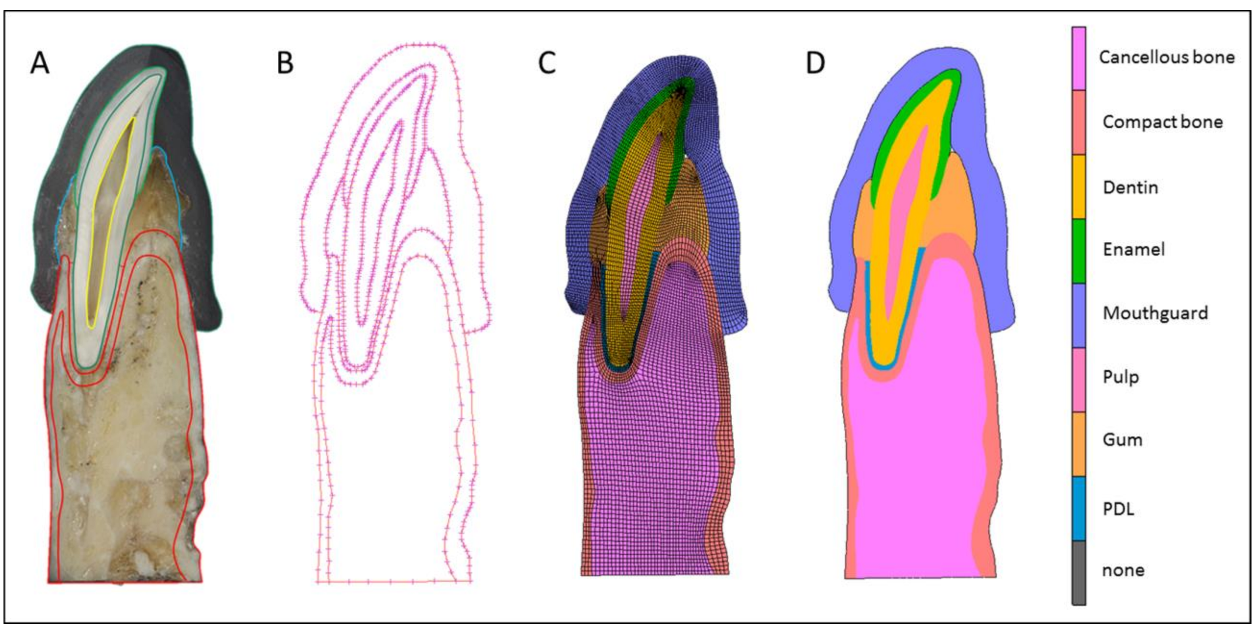

Figure 3- 2D Finite element modeling. A) Cross-section of the sample of the experimental bovine dentoalveolar model used to trace tissue outlines in ImageJ; B) Tissue outline curves in traced in finite element pre-processor through points imported from Image J; C) Finite element mesh; D) two-dimensional plane strain model of the sample used in the experimental test (non-bonded interface between mouthguard and the bovine model).

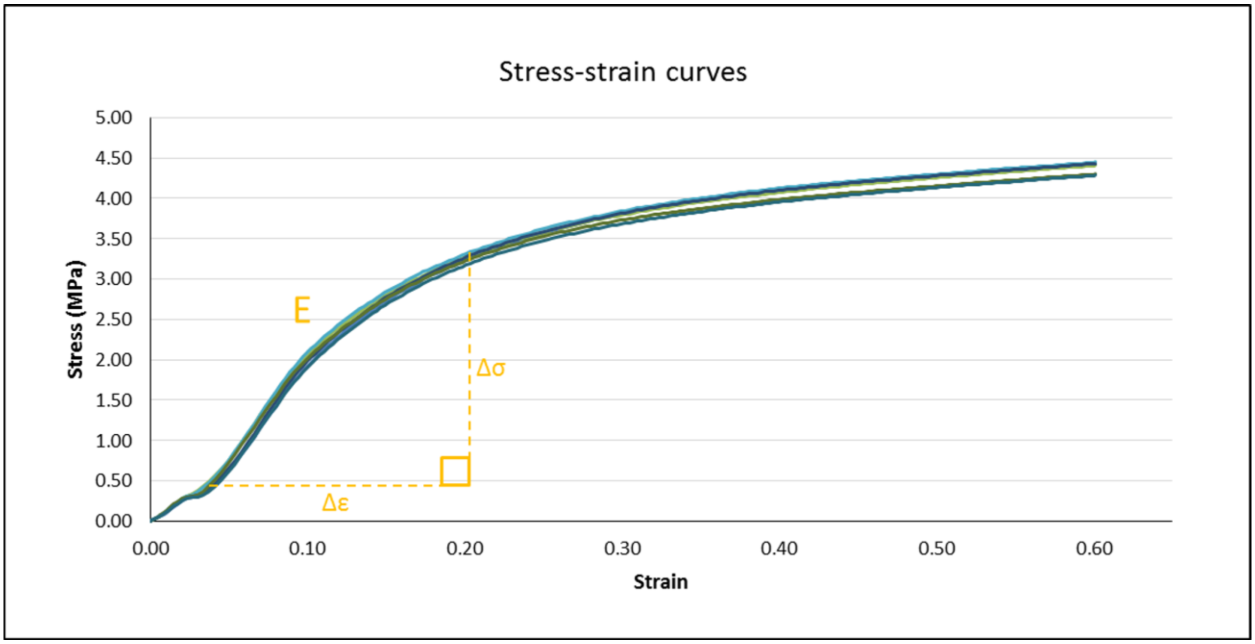

Figure 4- Stress-strain curves for the 0-150N load application, indicating the section where the elastic modulus was determined.

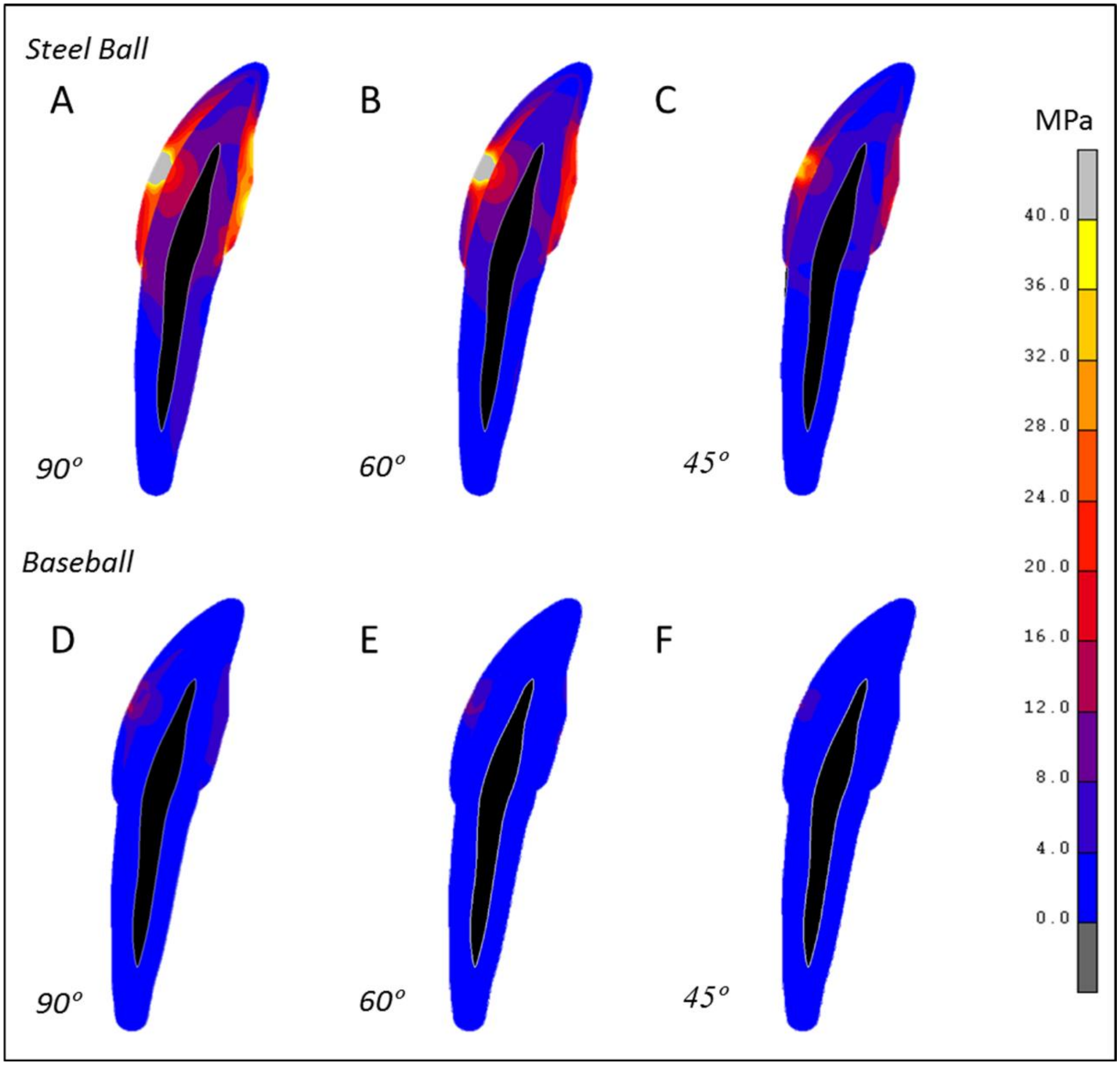

Figure 5- von Mises stress distributions at the peak of impact without mouthguard. A) Steel ball-90º; B) Steel ball-60º; C) Steel ball-45º; D) Baseball-90º; E) Baseball-60º and F) Baseball-45º.

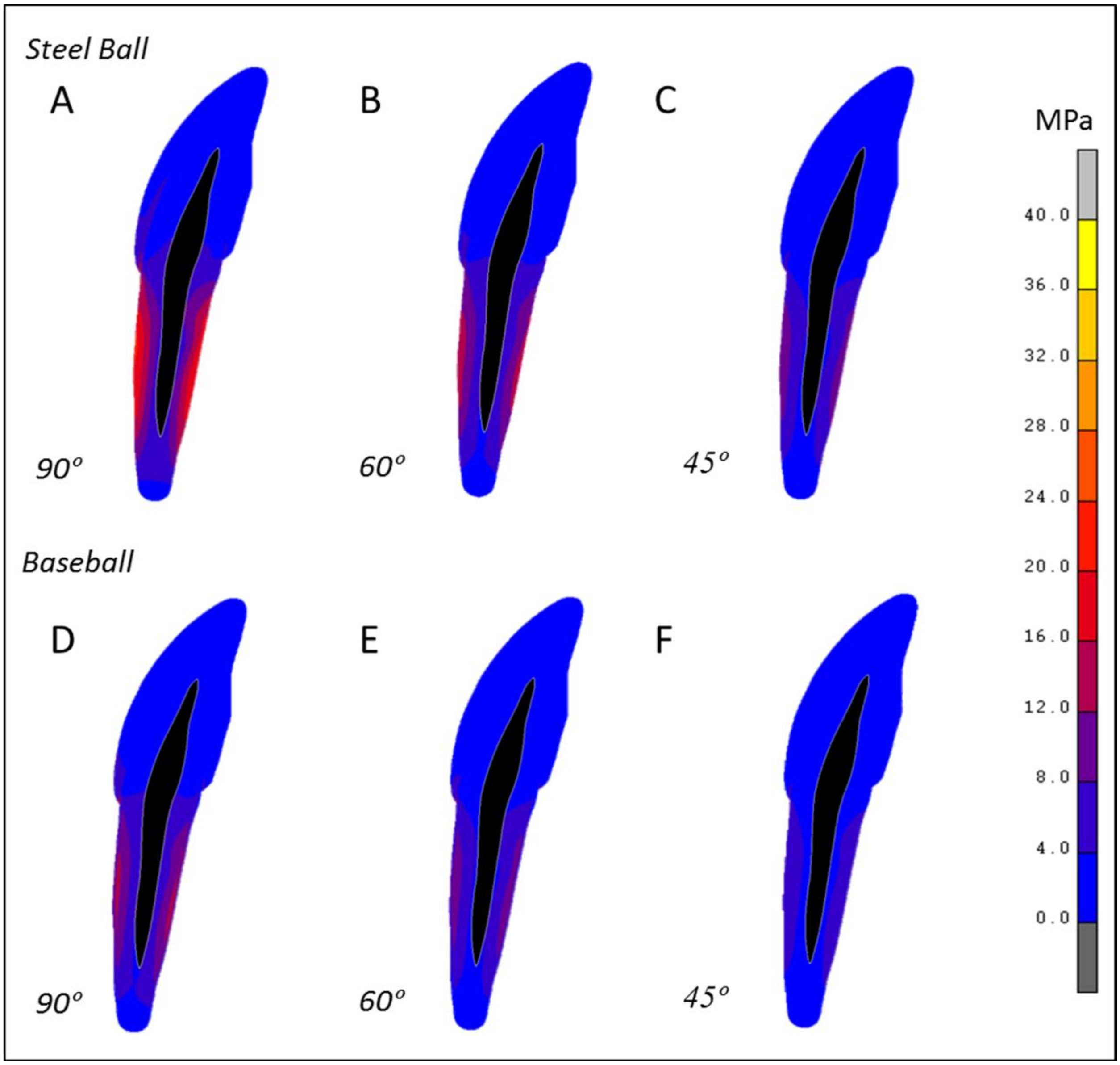

Figure 6- von Mises stress distributions at the peak of impact with mouthguard. A) Steel ball-90º; B) Steel ball-60º; C) Steel ball-45º; D) Baseball-90º; E) Baseball-60º and F) Baseball-45º.

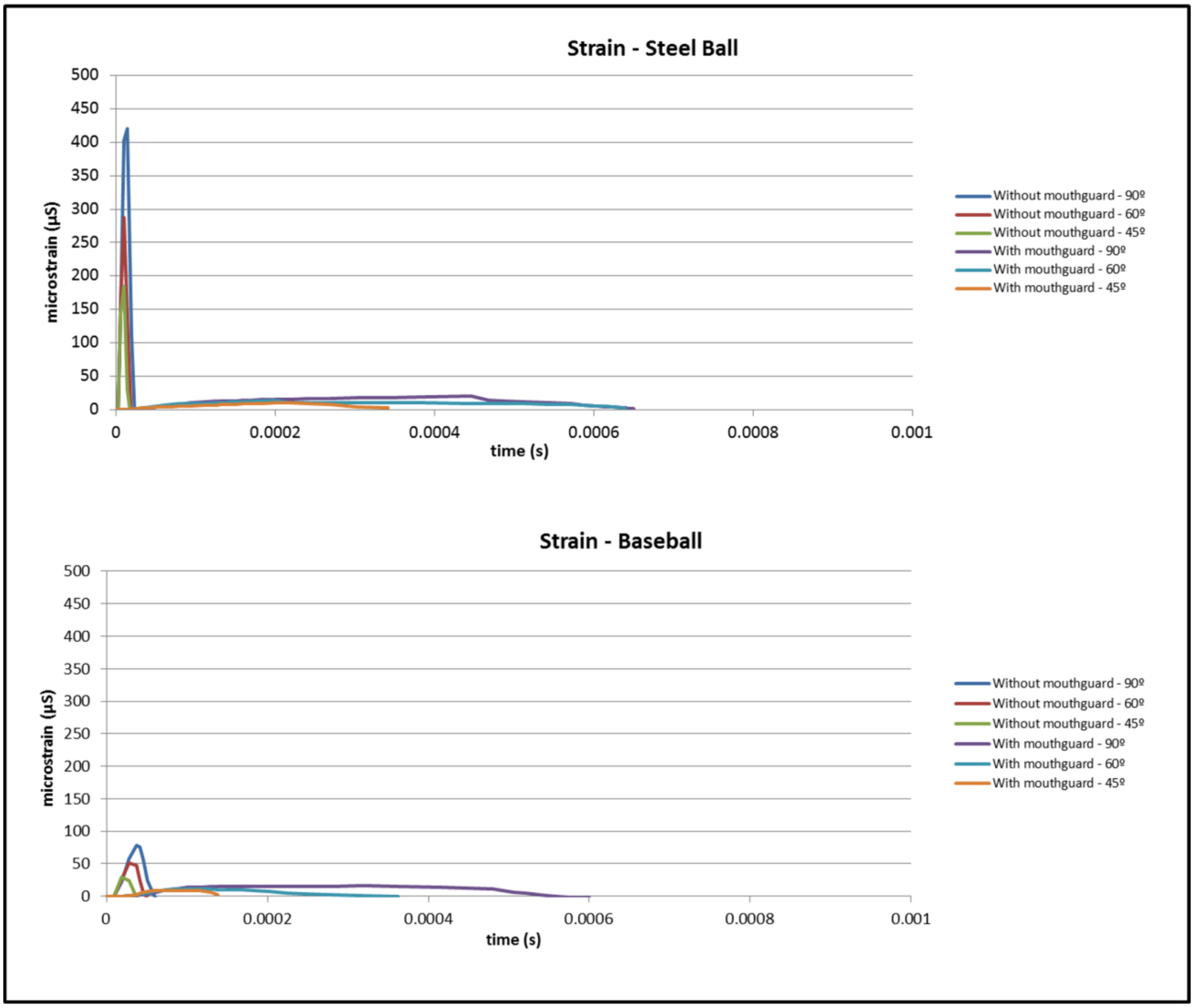

Figure 7- Microstrain values calculated by the finite element analysis during the impact simulation.

CAPÍTULOS

3.2 CAPÍTULO 2

Custom-Fitted EVA Mouthguards: What is the ideal thickness? A dynamic finite element impact study

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Title: Custom-Fitted EVA Mouthguards: What is the ideal thickness? A dynamic finite element impact study

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Abstract

Background: Mouthguards are devices used during sports practice to protect oral and facial structures from impact loads. Mouthguard thickness is inversely related with the shock absorption.

Purpose: The purpose of this study was to evaluate the tooth stresses and strains, shock absorption, and displacement during impact of custom-fitted mouthguards with different thicknesses.

Study Design: Controlled Laboratory Study.

Methods: The elastic modulus of the ethylene vinyl acetate (EVA) used for mouthguard fabrication was determined experimentally. Six bar-shaped specimens of the EVA were made and subjected to tension using a universal mechanical testing machine. The elastic modulus was determined from the calculated stresses and strains. Two-dimensional plane-strain models of a human maxillary central incisor, periodontal ligament, bone support, soft tissue, and mouthguard (MTG) were created based on a CT-tomography image of a patient wearing a mouthguard. The mouthguards were modeled in five different thicknesses (2, 3, 4, 5 and 6 mm). One model was created without mouthguard. A non-linear dynamic impact analysis was performed in which a heavy rigid object hit the model at 1 m/s. Strain and stress (von Mises and Critical modified von Mises) distributions were evaluated and the displacement of the mouthguard with respect to the tooth was calculated.

Results: The mean [standard deviation] for the EVA elastic modulus was 18.075 [0.457] MPa. The model without mouthguard showed the highest stress values at the enamel and dentin structures in the tooth crown during the impact. For the MTG models the location of the stress concentrations changed to the root, regardless of the MTG thickness, but maximum stresses in the enamel and dentin were lower compared with the model without MTG. Increasing the mouthguard thickness did not notably decrease the stress-strain values.

Conclusion: It was concluded that the use of a mouthguard promoted lower stresses and strains in teeth during an impact with a rigid object, and that there was no substantial difference in peak stresses and strains and in shock absorption among mouthguards that were 4 to 6 mm thick.

Clinical Relevance: Mouthguard thicknesses of 3-4 mm can be recommended for custom-fitted mouthguards fabrication and use during sports practice.

Keyword: Mouthguard; Biomechanics; Finite element analysis; Stress.

Introduction

The majority of oral-facial injuries are related with sports activities.[24-26] However, most of these injuries can be prevented by using protective devices, such as headgears, mouthguards (mouth formed, stock and custom-fitted), helmets, and protective facemasks.[5, 10, 19]. Mouthguards are specially designed for dental trauma prevention during contact sports.[6, 12, 14, 19] Their primary function is to prevent direct violent contact with tooth structures and between the upper and lower dentition. Mouthguards also absorb energy generated by the impact and reduce the forces transmitted to the teeth. Positive effects of mouthguards made from ethylene vinyl acetate (EVA) copolymer and their shock absorption ability have been shown in various studies.[4, 29] Among the different mouthguard types, custom-fitted mouthguards provided superior performance in terms of comfort, fit, stability, respiratory capacity, phonetics and protection for dental structures. [7, 8, 21]

Mechanical performance of mouthguards in terms of shock absorption is affected by several factors, such as: material type, geometry, manufacturing process and thickness. These factors also influence the fit, comfort and wearability.[15] Although these factors influence the mouthguard performance, the thickness is perhaps the most important parameter for shock absorption.[6, 31] The thickness of custom-fitted mouthguards can be influenced by heating and fixation during the manufacturing process, and by sheet geometry.[16, 17] Several studies reported that the shock absorption ability is improved by increasing the thickness.[18, 31, 32] On the other hand, thicker mouthguards are related with poor athletic performance, respiratory efficiency and comfort issues. Some authors reported that 4 mm seems to represent the ideal thickness to provide sufficient shock absorption and comfort.[7, 15, 31]

Experimental impact tests have been used to evaluate mouthguard performance.[9, 27, 28] However, internal stress distributions cannot be obtained from typical impact tests. Therefore, shock absorption mechanisms of mouthguards and stress distributions over the tooth structures are still unclear. Finite element analysis is a powerful engineering tool that can calculate the stress and strain behavior of the materials in response to load application. The aim of this study was to use finite element analysis for the evaluation of internal stresses and strains, shock absorption, and displacement of custom-fitted EVA mouthguards for different thicknesses (2, 3, 4, 5 and 6 mm).

Materials and Methods

Elastic modulus assessment of ethylene vinyl acetate (EVA)

Six bar-shaped specimens of the EVA (Bio-art, São Carlos, SP, Brazil) were made (70 x 10 x 3 mm). The specimens were attached to two pneumatic clamps (2712 Series Pneumatic Action Grips, Instron Corporation, Norwood, MA, USA). The initial length between the clamps was measured using a digital caliper before starting the test. The specimens were subjected to a nondestructive tensile load from 0 to 150 N at crosshead speed of 500 mm/min using a universal mechanical testing machine (Instron 5500 Series, Instron Corporation). The load/displacement data were recorded by dedicated software (BlueHill 2, Instron Corporation). The strain (ε) was calculated as the ratio of the displacement and initial length between the clamps and the stress (σ) was determined as the ratio of the load and cross-sectional area of each sample. The elastic modulus (E) was calculated from the middle portion of each stress-strain curve (avoiding the initial alignment slack of the clamps): $E = (\sum \Delta\sigma/\Delta\varepsilon)/N$, where $\Delta\sigma$ is a stress increment and $\Delta\varepsilon$ is a strain increment, and N is the number of data points. This mean elastic modulus of the six samples was applied in the finite element analysis.

Two-dimensional dynamic finite element impact modeling

Two-dimensional models of a human maxillary central incisor, periodontal ligament, bone support (cortical and trabecular bone), soft tissue, and mouthguard (MTG) were created based on a CT-tomography image of a patient with normal occlusion (Angle Class I) wearing a mouthguard (Fig. 1A). The image was exported to an image processing and analysis software (Image J, public domain, National Institute of Health, Bethesda, MD, USA) for tracing coordinates of the tissue outlines. The coordinates obtained (Fig. 1B) were imported in a finite element analysis program (Marc/Mentat, MSC software, Santa Ana, CA, USA) and cubic-spline curves were created through these coordinates to recreate the tissue outlines (Fig. 1C). A model without mouthguard (Without-MTG) and five models with mouthguards of different thicknesses were created (2mm-MTG, 3mm-MTG, 4mm-MTG, 5mm-MTG and 6mm-MTG) (Fig. 1D). The geometries of the mouthguards were created based on the CT image of a patient wearing a 3 mm custom-fitted MTG. By adjusting the original 3mm-MTG to 2, 4, 5, or 6 mm thickness we created the other MTG models. The element mesh was manually created using four-node isoparametric arbitrary quadrilateral plane strain elements with reduced integration (one integration point per element - element type number 115 in the Marc/Mentat software) (Fig. 1E).

Frictionless contact was prescribed between the mouthguard and the model interface and separation between them was allowed during the impact. All other interfaces were considered bonded. A dynamic impact analysis was performed using the Single-Step Houbolt method. This algorithm is recommended for implicit dynamic contact analyses.[3] A rigid impact object (steel) was simulated and a 1.0 m/s initial velocity was applied to all the nodes of the impact object in the x-direction (Fig. 1F), but the impact object was unrestrained after this initial velocity was applied. No gravitational forces were modeled. The nodes on the base of the bone structure were rigidly fixed in the x- and y-directions (Fig. 1F). All materials were considered linear, isotropic and homogeneous. The mechanical properties (elastic modulus, Poisson’s ratio and material density) are shown in Table 1.

Each model was solved in Marc, and the results were analyzed until the impact object lost contact with the mouthguard. During the analysis, a custom-made subroutine (Fortran-based) recorded the strain values in the Y direction for one node at the palatal side. Based on the peak strain values (maximum impact) the shock absorption capability was calculated for each mouthguard thickness, defined as the percentage of the peak value of the model without mouthguard. This program also recorded the 10% highest stresses in the enamel and dentin during the impact. The stress distributions were analyzed using von Mises equivalent stresses, which integrate all stress components into one stress equivalent value. Additionally, the Critical modified von Mises stresses were determined to show critical areas for structural failure at the height of impact. The Critical modified von Mises stress takes the difference between compressive and tensile strengths into account and scales the equivalent values relative to their tensile strength. The compressive and tensile strengths of enamel were 384.0 and 10.3 MPa and for dentin 297.0 and 98.7 MPa, respectively.[30]

Finally, the contact status between the mouthguard, tooth, and impact object was evaluated. The distances between nodes on the mouthguard and the tooth model (contact separation) were calculated during the impact analysis to characterize the mouthguard displacement (mm): $d = \sqrt{\{ (x2 - x1)^2 + (y2 - y1)^2\}}$, where d is the mouthguard displacement away from the tooth, x_1 and y_1 are the x- and y-coordinates of the node at the tooth surface, and x_2 and y_2 are the coordinates of a corresponding node on the mouthguard surface (Fig. 5A).

Results

Elastic modulus of EVA

The mean [standard deviation] for the EVA elastic modulus was 18.075 [0.457] MPa. This value was used in the finite element analysis.

Dynamic finite element impact analyses

Stress distributions in the model without MTG and in the different MTG models at the peak of the impact are shown in Figure 2. The stress values are visualized according to a linear color scale: blue indicating the lowest stress values, yellow and light gray the highest stress values. The mean of the 10% highest stresses for enamel and dentin during the impact analysis are shown in Figures 2G and 2H. The model without mouthguard had the highest stress values at the enamel and dentin structures in the tooth crown during the impact (Figs. 2A, 2G, and 2H). For the MTG models the location of the stress concentrations changed to the root, regardless of the MTG thickness, and maximum stresses in the enamel and dentin were lower than they were in the model without MTG (Figs. 2B-2F). Increasing the mouthguard thickness did not notably decrease the stress values (Fig. 2G and 2H).

The history plot for the strain values at the palatal side of the tooth and the strain peak values are shown in the Figure 3. The model without MTG showed a high strain value compared to the MTG models (Fig. 3A). Among the models with mouthguard, the 2 mm thick mouthguard exhibited the highest strain values and lowest shock absorption (Fig. 3B). The history plot showed that the time to reach the peak strain was longer with the 3 and 4 mm mouthguards, but further increasing the thickness to 5 or 6 mm yielded similar times to peak as found for the 2mm-MTG model (Fig. 3A).

The distribution of the Critical modified von Mises stress showed that for the model without mouthguard the critical area for structural failure at impact was at the palatal side (Fig. 4A). The path plot of the mouthguard displacement for each MTG model is shown in Figure 5. The different mouthguard thicknesses resulted in different patterns of mouthguard displacements. Increasing the mouthguard thickness decreased the mouthguard displacement on the buccal side at the end of the impact. The 2mm-MTG and 3mm-MTG showed higher displacement at the buccal side. The 6mm-MTG showed lower displacement at the buccal side.

Discussion

Mouthguard thickness is one of the most important contributing factors for the mechanical performance and shock absorption ability of mouthguards. The standard method for custom fitted mouthguard production is to press a sheet of thermoplastic material against a plaster model by means of a vacuum forming machine. Several studies showed the influence of the fabrication process (holding and heating process) on the final thickness of a mouthguard. Different techniques have been developed to ensure optimal final thickness during the manufacturing process.[16, 17] Mouthguards with thicknesses ranging from 2 to 6 mm have been evaluated in the literature. Most recent studies show that 3 or 4 mm thickness provides sufficient protection and comfort during the use.[18, 31, 32] Impact testing has extensively demonstrated that the mouthguard thickness has an inverse relationship with the force transmitted.[31] Nevertheless, experimental impact tests cannot show the stresses and strains that are generated internally in the tooth structure and in the bone support during an impact.

Finite element analysis may be the only approach that can predict stress and strain behavior of the materials and structures during impact load. This study used a non-linear dynamic finite element impact analysis to evaluate the stress distributions and strains assuming a plane strain condition in the structures. This engineering term identifies a special three-dimensional stress condition that may occur in structures where the strain perpendicular to the cross-sectional plane is zero.[30] Dynamic analyses are different from more common static analyses because at high loading rates the inertia forces cannot be neglected. In the current dynamic analysis, the impact object's velocity and inertia were the initial conditions that determined the time-dependent forces to which the tooth and mouthguard models were subjected. Besides the dynamics, the interface between the impact object, mouthguard, and tooth are also important for a realistic impact response. In most of the previously published finite element analyses the tooth and mouthguard elements shared the same nodes at their interfaces, which means that they were perfectly bonded. However, in reality mouthguards are not bonded to the tooth surface nor the soft tissues. The current study applied non-linear contact analysis between the impact object, mouthguard and tooth model to predict their interactions and displacements more accurately during the impact.

The results of the finite element analysis showed that the mouthguards reduced maximum stress and strain values in both enamel and dentin for all thicknesses. The compliant EVA material of the mouthguards absorbed most of the impact deformation, which increased the time to absorb and redistribute the impact forces and thus decreased the stress and strain on the tooth structure. The presence of a mouthguard therefore allowed the stresses caused by the impact to be distributed through the dentin structures into the bone, which resulted in lower strain values at the palatal side of the crown. This behavior can be observed in Figure 2. Preliminary studies determined that the relationship between the deformation of teeth with or without mouthguard is a good indicator for the efficiency of these devices in terms of design and ability to prevent traumas.[27] In our study, a higher strain value was obtained with the 2 mm thick mouthguard and consequently its shock absorption ability was lower than with the thicker mouthguards. With each increase in mouthguard thickness, the peak strain value decreased slightly up to the 5 mm thickness, after which a small increase in peak strain was noted for the 6mm-MTG. Apparently, beyond 5 mm the structural stiffness and inertia increase of the mouthguard caused by the added thickness became more influential than the absorption offered by the thicker EVA layer. This mechanism can be seen in the reduction in bounce-back time of the impact object (Fig. 3A).

Crown fracture without pulp exposure is the most frequent dental trauma injury, with an occurrence of 36% compared to 24% concussion and 22% subluxation.[13] Therefore, information related to location and propagation of crown facture is vital for treatment, prognosis and prevention of dental traumas. We used the Critical modified von Mises to assess the critical areas for structural failure. We observed that an impact load horizontal to the dentition and without mouthguard created a potentially critical condition for fracture at the palatal side of the tooth crown (Fig. 4A). This stress condition implies bending of the crown at impact, causing compression in the enamel on the buccal side and (critical) tension in the enamel at the palatal side. Presence of mouthguard prevented this critical condition regardless of the mouthguard thickness.

Custom-fitted mouthguards are individually made and thus offer advantages in terms of comfort, fit, stability, phonetics and respiratory capacity.[7] Mouthguard displacement is an important parameter for the impact absorption since a mouthguard should stay in position to function correctly. The dynamic finite element impact analysis in this study showed that there is a relationship between the mouthguard thickness and the pattern of mouthguard displacement. Thin mouthguards (2 and 3 mm) have higher displacements at the buccal side. These suggests that a thicker mouthguard can prevent mouthguard displacement during an impact. However, other factors, such as soft tissues, proximal areas, and tooth surfaces are involved in the mouthguard retention and fit. Further research using three-dimensional (3D) modeling may be necessary to further study these relationships.

The balance between mouthguard thickness and its comfort is critical for athletic performance and wearing compliance. Thick mouthguards (6 mm) are likely to cause discomfort, respiratory issues, and have poor acceptance.[15] Lips and cheeks are the natural barriers that help to protect the teeth from a direct impact. However, a 6 mm mouthguard can jeopardize this natural protection and not allow the lips to cover the teeth.[15] Furthermore, thicker mouthguards can increase the tension between the lips and cheeks, which increases the risk of soft tissues injuries. From the present study it can be concluded that the use of a mouthguard promoted lower stresses and strains in teeth during an impact with a rigid object, and that there was no substantial difference in peak stresses and strains and in shock absorption among mouthguards that were 4 to 6 mm thick. In addition, increasing mouthguard thickness decreased the mouthguard displacements. Considering the results of the finite element impact analysis and the discussed concerns about comfort, mouthguard thicknesses of 3-4 mm can be recommended for custom-fitted mouthguards.

Acknowledgements

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Table 1. Mechanical properties applied for the dental structures and materials.

Structure	Elastic Modulus (MPa)	Poisson's ratio	Density (g/cm^3)	References
Enamel	84,100	0.30	2.14	[33]
Dentin	18,600	0.30	2.97	[23]
Periodontal ligament	50	0.45	0.95	[22]
Trabecular bone	1,400	0.31	0.70	[2]
Cortical bone	13,700	0.33	2.00	[2]
Soft tissue	1.8	0.30	0.95	[11]
Steel	200,000	0.30	7.8	[1]
EVA	18.075*	0.30	0.95	[20]

*Experimentally determined in this study

Figures

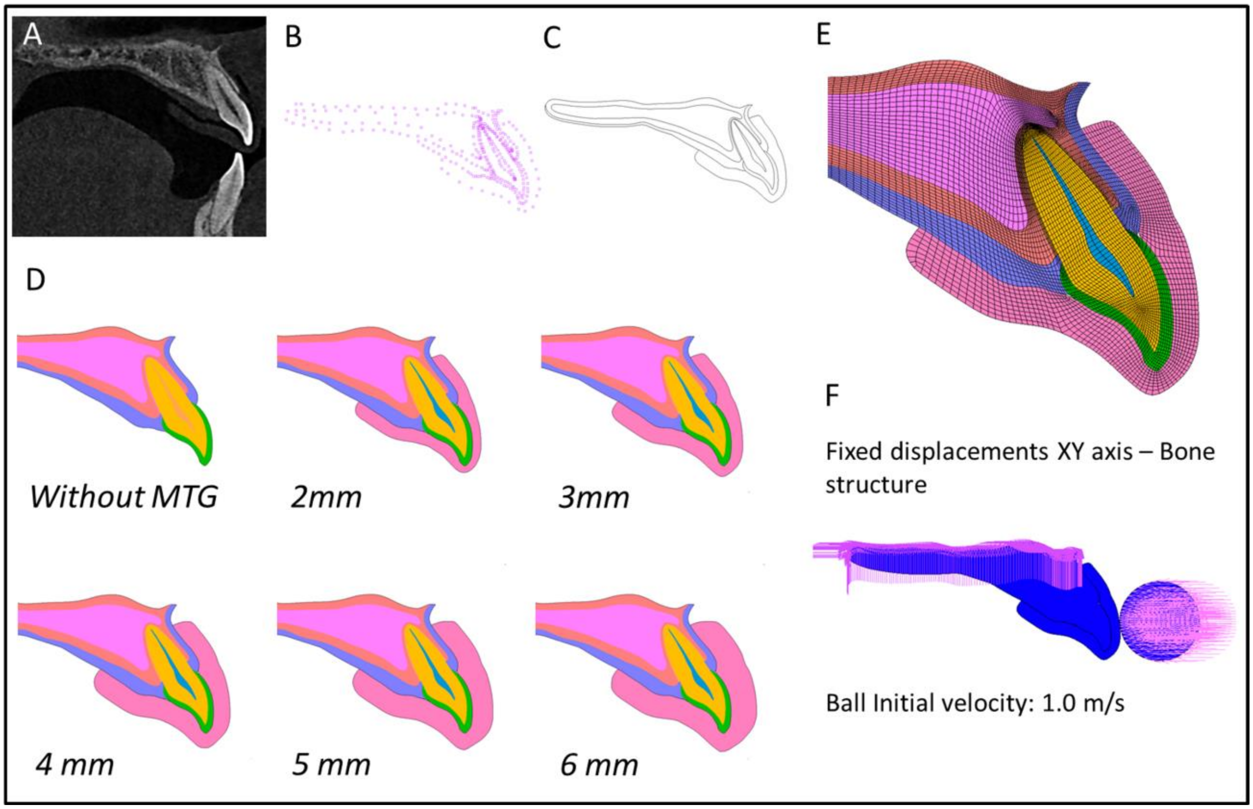

Figure 1. Generation of two-dimensional finite element models. A) CT-tomography image of maxillary central incisor with MTG; B) coordinates points of the CT image imported from Image-J; C) Cubic-spline generated from the coordinates; D) Two-dimensional models created without mouthguard and with 2, 3, 4, 5, and 6 mm thick mouthguards; E) finite element mesh distribution (with 3 mm thick mouthguard); F) Boundary conditions.

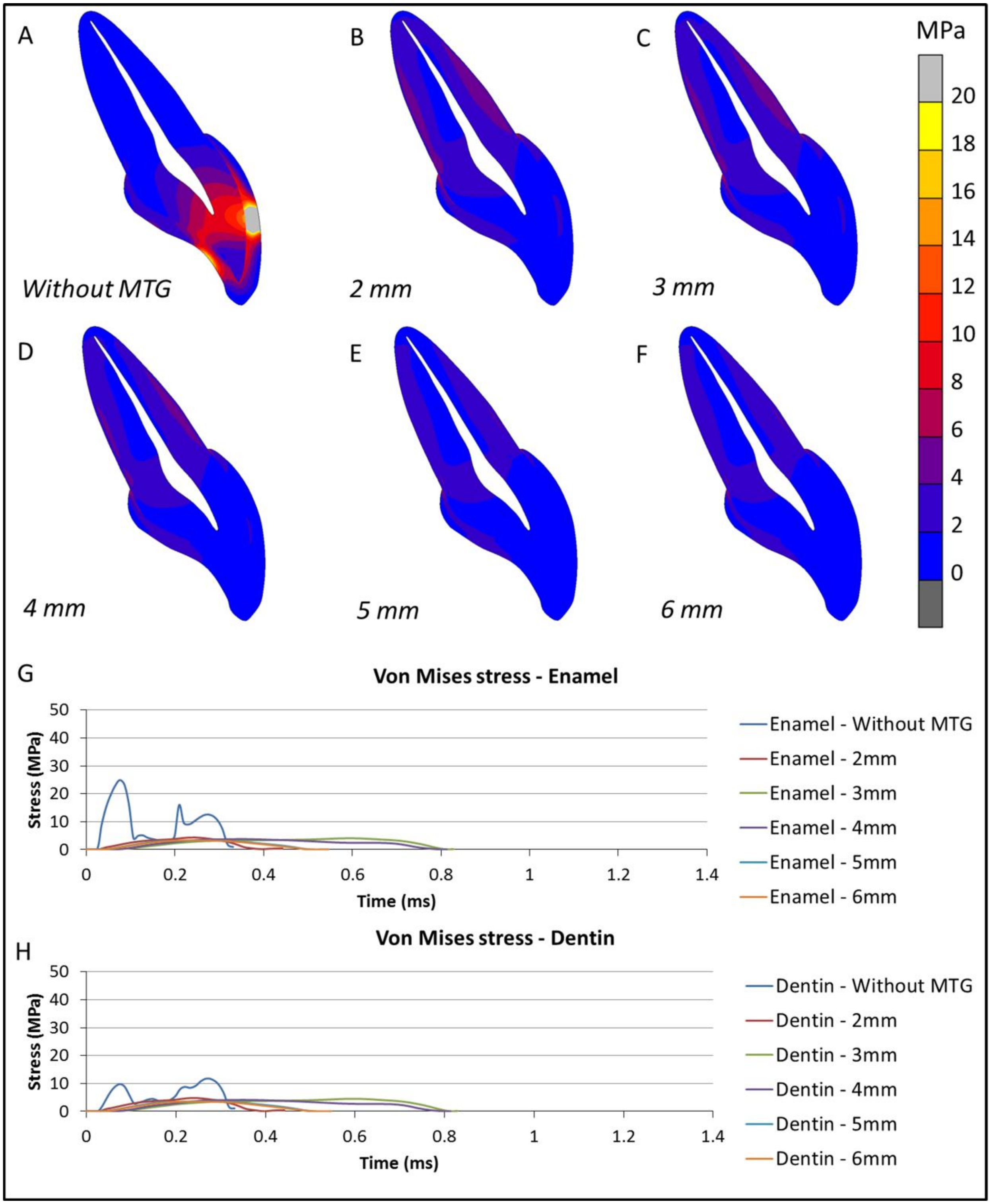

Figure 2. Von Mises stress distributions at the peak of impact A) Without MTG; B) 2 mm-MTG; C) 3 mm-MTG; D) 4 mm-MTG; E) 5 mm-MTG; F) 6 mm-MTG; G) mean of

10% highest stress values for enamel; H) mean of 10% highest stress values for dentin during the impact.

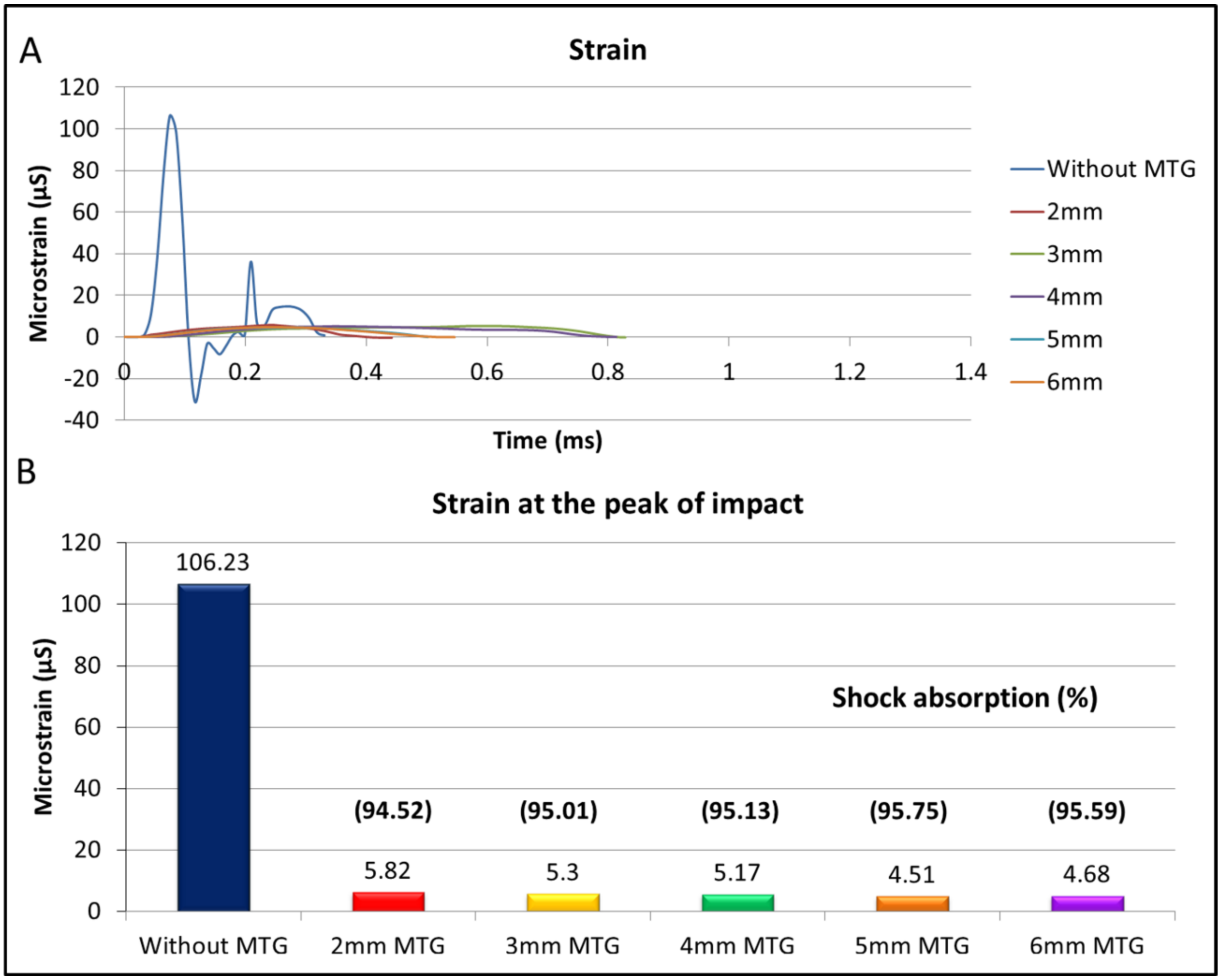

Figure 3. Strain values at the palatal side of the tooth. A) History plot during the impact; B) Microstrain values at the peak of impact and percentage shock absorption in parentheses.

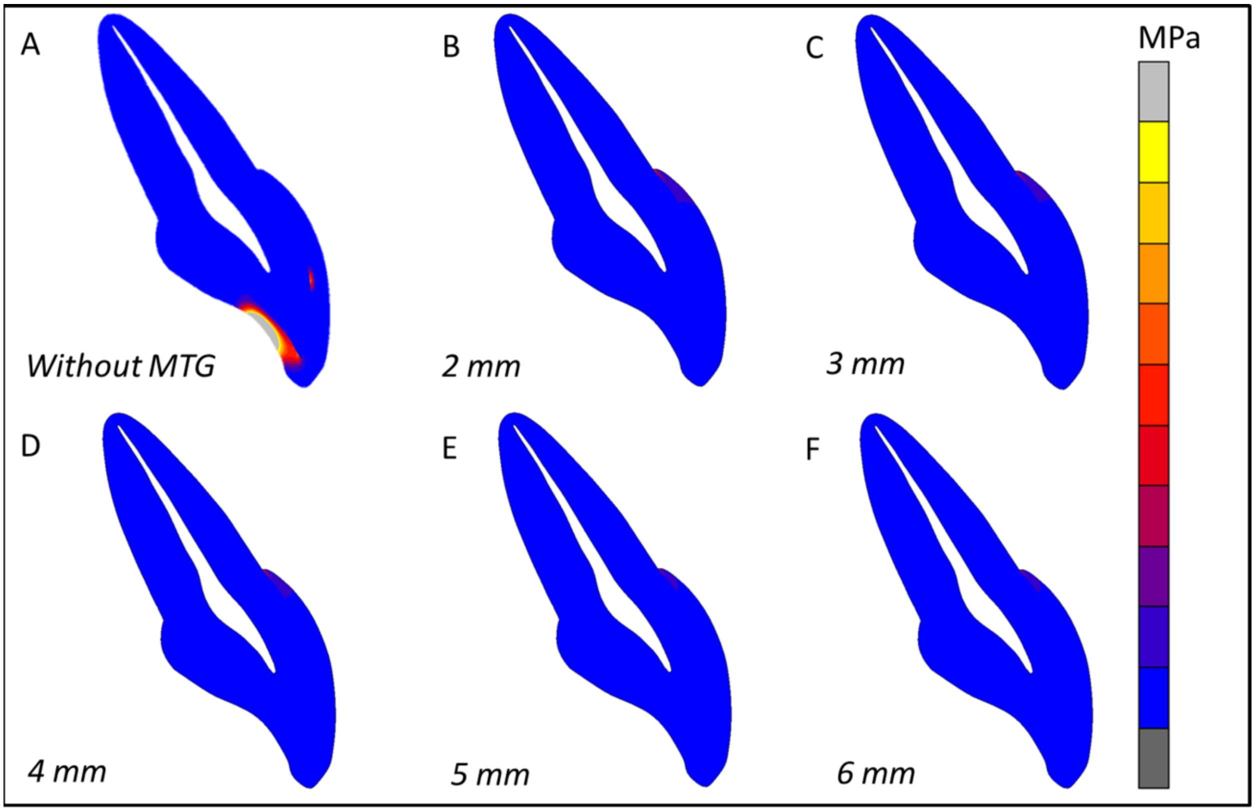

Figure 4. Critical modified von Mises stress distributions at the peak of impact. A) Without MTG; B) 2mm-MTG; C) 3mm-MTG; D) 4mm-MTG; E) 5mm-MTG; F) 6mm-MTG.

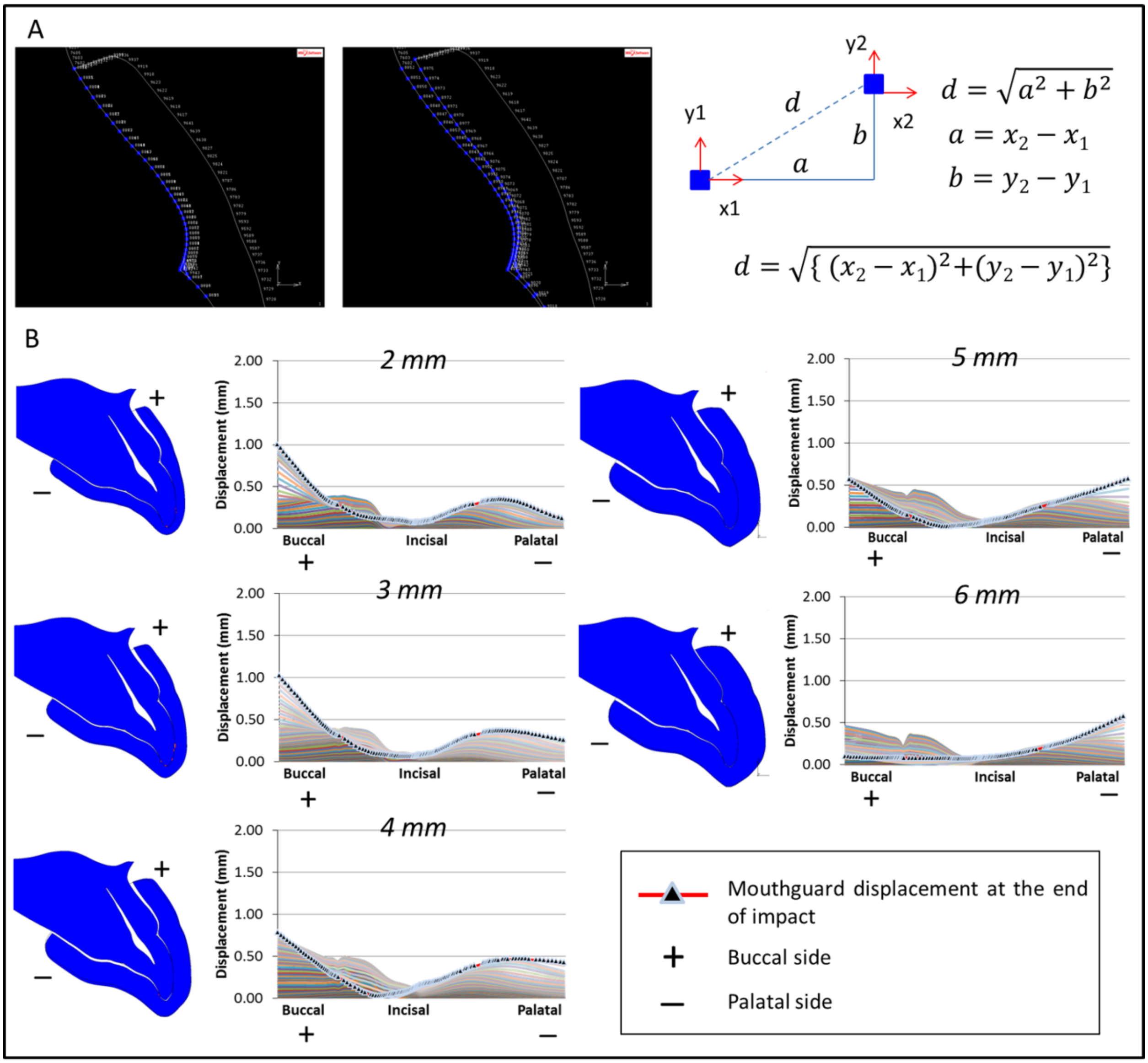

Figure 5. Path plot of the mouthguard displacement (mm) during the impact application.

CAPÍTULOS

3.3 CAPÍTULO 3

Modifying the biomechanical response of mouthguards with hard inserts: a finite element study

Artigo aceito para publicação no periódico American Journal of Dentistry

Title: Modifying the biomechanical response of mouthguards with hard inserts: a finite element study

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Modifying the biomechanical response of mouthguards with hard inserts: a finite element study.

Abstract

Purpose: To investigate the influence of a high elastic modulus material insert on the stress, shock absorption and displacement of mouthguards. **Methods:** Finite element models of a human maxillary central incisor with and without mouthguard were created based on a cross-sectional CT-tomography. The mouthguard models had four designs: without insert, and middle, external, or palatal hard insert. The hard inserts had a relatively high elastic modulus when compared to the elastic modulus of ethylene vinyl acetate (EVA): 15 GPa versus 18 MPa. A non-linear dynamic impact analysis was performed in which a heavy rigid object hit the model at 1 m/s. Strain and stress (von Mises and Critical modified von Mises) distributions and shock absorption during impact were calculated as well as the mouthguard displacement. **Results:** The model without mouthguard had the highest stress values at the enamel and dentin structures in the tooth crown during the impact. It was concluded that the use of a mouthguard promoted lower stress and strain values in the teeth during impact. Hard insertion in the middle and palatal side of the mouthguard improved biomechanical response by lowering stress and strain on the teeth and lowering mouthguard displacement.

Clinical Significance. Mouthguards are protective devices that can be used to decrease the likelihood of dental trauma from impact. Dental practitioners should recommend mouthguards for their patients during contact sports practice. Mouthguards

with middle hard insertions combine lower stress and strain values with lower displacements and thus better retention during impact.

Keywords: Finite Element Analysis; Impact; Stress; Strain; Mouthguard; Biomechanics.

Introduction

Mouthguards are devices used to reduce the likelihood of dental and orofacial injuries during contact sports.[1] According to Reed[2], the first attempt of making a device for protecting oral structures in sports was made in 1890, when a British dentist Wolf Krause used two layers of gutta-percha attached to the upper teeth of a professional pugilist. The history of the mouthguard reveals that the creation of these devices was based on empiricism and clinical experience. Mouthguard devices function by preventing direct violent contact against teeth and reducing the harmful effects contact forces by absorbing the impact energy.[3-5]

Different polymers have been used for mouthguard fabrication.[6, 7] Ethylene-vinyl acetate (EVA) copolymer, polyvinyl chloride, natural rubber, acrylic resin and polyurethane (sorbothane) have been used for their compliant (often incorrectly referred to as elastic) properties.[8, 9] EVA, with 18-28% of vinyl acetate, may be the most common material for mouthguard.[10] Their shock absorption ability and thus the positive effects on mouthguards have been shown in several studies.[7, 11] To further increase the effectiveness of mouthguards, various approaches have been proposed, including laminate layering, air-cells, or hard acrylic resin inserts.[12-15] However, there is no consensus which mouthguard design provides a better stress distribution in the tooth structure during an impact.

Experimental impact tests based on pendulum devices are most often used to evaluate mouthguard performance.[16-18] Although these experiments offer valuable information, they cannot provide details about the internal behavior of materials, such as the stress distributions in the tooth-bone complex needed to understand and optimize mouthguard designs. Such information can be obtained by finite element analysis, which is a powerful engineering tool used to study stress and strain behavior in response to load application.[19] This numerical method incorporates structural design to calculate stress and strain responses by solving the relevant physical equations in a computational analysis.

The aim of this study was to evaluate the internal stresses and strains, shock absorption, and displacement of EVA mouthguards with a hard material inserted in different positions: middle, external, and palatal. The evaluation was carried out using non-linear finite element impact analysis simulating impact on a human maxillary central incisor model. The impact responses were compared to a model without mouthguard and a model with a mouthguard without hard insert.

Materials and Methods

Geometrical models of a human maxillary central incisor, periodontal ligament, bone support (cortical and trabecular bone), soft tissue, and mouthguards were created based on a cross-sectional CT-tomography image of a patient with normal occlusion wearing a mouthguard (Fig. 1A). Coordinates of the tissue outlines were traced in two dimensions with an image processing and analysis software (Image J, public domain, National Institute of Health, Bethesda, MD, USA) and imported in a finite element analysis program (Marc/Mentat, MSC software, Santa Ana, CA, USA). Cubic-spline curves were created through these coordinates to recreate the tissue outlines. One model without mouthguard (Fig. 1B) and four models with 3 mm thick EVA mouthguards were generated. Of these four mouthguard models, one was without insert (uniform EVA elastic modulus), and 3 had a higher elastic modulus material inserted in the middle, externally, or at the palatal side (Fig. 1C). The middle and external inserts were 1 mm thick. The palatal insert was covered with a thin layer (0.35 mm) of the more pliable EVA material at the soft tissue contact surface for comfort reasons. Therefore the thickness of the palatal hard insert was 2.65 mm. The element mesh was manually created using four-node isoparametric arbitrary quadrilateral plane strain elements with reduced integration (one integration point per element), which was element type number 115 in the Marc/Mentat software (Fig. 1D).

Frictionless contact was prescribed between the mouthguard and the model interface, allowing separation between them during the impact. All other interfaces could not separate. A dynamic impact analysis was performed using the Single-Step Houbolt method for implicit dynamic contact analysis.[20] A rigid impact object, which was given the properties of steel, was simulated with a 1.0 m/s initial velocity in the x-direction (horizontal) (Fig. 1E). The impact object was unrestrained in its path after this initial velocity was applied. No gravitational or air-friction forces were modeled, thus the path and of the impact object was determined by its inertia and the contact and response of the impacted model with or without mouthguard. The nodes on the base of the bone structure were rigidly fixed in the x- and y-directions (Fig 1E). All materials were considered linear, isotropic and homogeneous. The mechanical properties (elastic modulus, Poisson's ratio and material density) are shown in Table 1. The elastic modulus of EVA had been experimentally determined from stress-strain curves in tensile tests. An arbitrary high elastic modulus of 15,000 MPa, similar to the elastic modulus range of restorative composites, was prescribed for the hard inserts.

Each model was solved in Marc (MSC software). The impact response was recorded until the impact object lost contact when it bounced off the mouthguard. During the analysis, a custom subroutine recorded the strain values in the y-direction (vertical) for one node at the palatal side of the crown to calculate the shock absorption, the stresses in enamel and dentin, and the model displacements. Shock absorption was defined as the percentage of the peak strain of the model without mouthguard. While recording the stresses, the subroutine determined the average value of the 10% highest von Mises equivalent stresses during the impact and calculated the Critical modified von Mises stresses as well. Von Mises stresses were used as an indication for the stress energy, whereas Critical modified von Mises stresses identified critical areas for structural failure due to the impact loads. Unlike von Mises stresses, the Critical modified von Mises stress takes the difference between compressive and tensile strengths into account and scales the resulting equivalent stress value in each material relative to its tensile strength. The compressive strengths were 384.0 and 297.0 MPa for enamel and dentin, respectively, and the tensile strengths 10.3 and 98.7 MPa.[19] The model displacements were used to monitor the mouthguard displacement with respect to the tooth. The distances between the mouthguard and tooth along their interfaces during the impact were calculated using: $d = \sqrt{\{(x2 - x1)^2 + (y2 - y1)^2\}}$, where d is the mouthguard displacement away from the tooth, x_1 and y_1 are the x- and y-coordinates of the node at the tooth surface, and x_2 and y_2 are the coordinates of a corresponding node on the mouthguard surface.

Results

Von Mises stress distributions in the model without mouthguard and in the different mouthguard designs at the peak of the impact are shown in Figure 2. The stress values are visualized using a linear color scale in which blue indicates the lowest stress values, and yellow and light gray the highest values. The mean of the 10% highest stresses for enamel and dentin during the impact event are shown in Figure 2F. The model without mouthguard had the highest stress values at the enamel and dentin structures in the tooth crown during the impact (Fig. 2A and 2F). For the mouthguard models the location of the stress concentrations changed to the root regardless of the position of the hard inserts, and maximum stresses in the enamel and dentin were lower than in the model without mouthguard. The mouthguard with the external hard insert showed higher stress values in the root compared to the other mouthguard designs (Fig. 2D).

The history plot for the strain values at the palatal side of the tooth and the strain peak values are shown in the Figure 3. The model without mouthguard showed a high strain value compared to the mouthguard models (Fig. 3A). Among the mouthguard designs, the model with the hard insert placed externally exhibited the highest strain values and lowest shock absorption (Fig. 3B). The history plot showed that the time to reach the peak strain was longer with the mouthguard with the hard insert in the middle. The palatal insert and the mouthguard without insert reached the peak at similar times, whereas the external insert reduced the time to reach the peak of impact (Fig. 3A).

The distribution of the Critical modified von Mises stresses showed that for the model without mouthguard the critical area for failure at impact was at the palatal side of crown (Fig. 4A). The path plot of the mouthguard displacement for each model is shown in Figure 5. The different designs affected the displacement pattern. The middle and external hard inserts decreased the mouthguard displacement on the buccal side at the end of the impact, while the mouthguard without insert and the one with a palatal insert showed more displacement on the buccal side.

Discussion

Despite the protection offered by a mouthguard, dental and orofacial injuries still happen. A simple way to improve the shock absorption of a mouthguard is to increase mouthguard thickness, which has been shown to decrease the force transmitted to the tooth.[21] However, there is a limit to how much the thickness of a mouthguard can be increased before it starts to negatively affect athletic performance and acceptance by the athletes. Moreover, it has been suggested that beyond an optimal thickness of 3-4 mm[21], the shock absorption may reduce due to increased overall mouthguard stiffness. Material choice is another option for improving the performance of mouthguards since a variety of polymers are available for mouthguard fabrication.[6] However, those choices are also limited by thickness. Another approach is combining of different materials while maintaining the ideal thickness around 3-4 mm. Previously improvements in shock absorption using air-cells[15], hard acrylic inserts [22], metal inserts[23], and hard inserts and interfacial spaces[22] have been reported. However, most studies were based on experimental models and could not evaluate the stresses and strains that are generated internally in the tooth structure during an impact. This study used finite element analysis to study internal stresses and strains during impact for gaining better understanding of the impact process and design factors that may improve mouthguard shock absorption.

The non-linear dynamic finite element impact analysis in this study assumed a plane strain condition in the cross-section. This assumption allowed us using a two-dimensional model, which improved model resolution without insurmountable computational costs of these demanding analyses. Plane strain is a special three-dimensional stress condition that may occur in structures where the strain perpendicular to the cross-sectional plane is zero.[19] Often quasi-static analyses have been used in impact studies. Dynamic analyses are different because at they take inertia forces into account that are important at high loading rates. In the current dynamic analysis, the initial velocity and inertia of the impact object determined the time-dependent forces on the tooth and mouthguard models. Another important aspect for a realistic impact response in the finite element analysis was how the interfaces between impact object, mouthguard, and tooth were modeled. In many of previous finite element studies the tooth and mouthguard elements shared the same nodes at their interfaces, thus in effect they were perfectly bonded. In reality, however, mouthguards are not bonded to the teeth or soft tissues. The current study applied contact analysis between the impact object, mouthguard and tooth model for more accurate interactions and displacements. . Using these modeling choices, we could analyze and contrast varies mouthguard designs by varying the value and distribution of their elastic modulus. The value of 15,000 MPa was chosen to be three orders of magnitude higher than the elastic modulus of the EVA mouthguard base material (18 MPa). Using this relationship we designed three mouthguard types that combined the pliable behavior of EVA with a stiff core material (here referred to as 'hard insert').

The results of the finite element analysis showed that the presence of mouthguards, regardless of the hard inserts, reduced maximum stress and strain values in both enamel and dentin. The mouthguard absorbed most of the impact deformation, which increased the time to distribute the impact forces, thus decreasing the stresses and strains in the tooth structure. The presence of a mouthguard also allowed the impact stresses to be better transferred through the dentin structures into the bone, which resulted in lower strain values at the palatal side of the crown. This behavior can be observed in Figure 2. The hard insertions slightly modified the stress, strain and mouthguard displacements. Placing the hard insert in the middle of the mouthguard further increased the time to reach the impact peak compared to the palatal hard insert or the mouthguard without an insert. On the other hand, the external hard insert created a stiffer mouthguard that resulted in a shorter time to reach the impact peak than the other mouthguard designs. This also explains why the external hard insert model had higher stress concentrations in the root compared to the other mouthguard designs. Besides stress, deformation of teeth is also a good indicator for the efficiency of mouthguards.[16] In the present study, a higher strain value obtained with the external hard insert and indicated the lower shock absorption ability of this design.

The Critical modified von Mises stress distribution was used to assess the critical areas for tooth fracture during an impact. Upper central incisors are frequently subjected to trauma and crown fractures.[24] these aesthetic areas are challenging to restore.

Therefore, the information related to location and propagation of crown facture is vital for treatment, prognosis and prevention of dental traumas. We observed that an impact load horizontal to the dentition, especially without mouthguard, created a potentially critical condition for fracture at the palatal side of the tooth crown (Fig. 4A). This stress condition implies bending of the crown at impact, causing compression in the enamel on the facial side and (critical) tension in the enamel at the palatal side. The presence of a mouthguard prevented this critical condition regardless the design.

Injury can still occur if a mouthguard is not well adapted to the teeth and oral tissues, and does not stay in position during the impact. Mouthguard displacement is thus also an important parameter for a properly functioning design and comfort during use.[25] Our dynamic finite element impact analysis showed a relationship between the hard inserts and the mouthguard displacement. The model without insert (solid EVA) and the model with a palatal hard insert had higher displacements on the buccal side (Fig. 5). On the other hand, the external and middle hard inserts had lower displacements on the buccal side. Since minimal buccal displacements are more important for mouthguard stability than palatal displacements, these results suggest that an external and middle insert may help prevent mouthguard displacement during an impact while maintaining an ideal thickness of around 3 to 4 mm. Apparently, improving shock absorption of mouthguards does not have to compromise wearability or athletic performance. Our model could not test all factors. Other factors such as soft tissues, proximal areas, and tooth surfaces are also involved in mouthguard retention and fit. Further research using three-dimensional (3D) modeling may be necessary to further study these relationships.

In this theoretical finite element study, we found that hard inserts influenced the mechanical behavior of mouthguards. All mouthguard models showed satisfactory shock absorption of more than 90% of the impact deformation. Placing a hard (stiff) insert in the middle of an EVA mouthguard provided the best results since it combined a higher time to reach the peak of impact, lower stress and strain values, and lower mouthguard displacements at the buccal side. The positive effects of a hard insert in the middle of the mouthguard have also been reported by Takeda *et al* using experimental impact tests.[22] The mouthguard with a palatal insert had more displacement at the buccal side during impact and a shorter time to reach the peak of impact than the middle insert design. The external insert, although it performed well for shock absorption, resulted in a stiffer mouthguard that allowed higher stresses and strains in the tooth structure than the other mouthguard designs. Moreover, a rigid material in contact with the lips and soft tissue may more readily cause lacerations at impact. In conclusion, inserting a hard material in the middle of the mouthguard improved the protective properties and should be recommended in mouthguard fabrication.

Acknowledgements

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Tables

Table 1. Mechanical properties for the dental structures and materials applied in the finite element impact analysis.

Structure	Elastic Modulus (MPa)	Poisson's ratio	Density (g/cm^3)	References
Enamel	84,100	0.30	2.14	[26]
Dentin	18,600	0.30	2.97	[27]
Periodontal ligament	50	0.45	0.95	[28]
Trabecular bone	1,400	0.31	0.70	[29]
Cortical bone	13,700	0.33	2.00	[29]
Soft tissue	1.8	0.30	0.95	[30]
Steel	200,000	0.30	7.80	[31]
EVA	18*	0.30	0.95	[32]
Hard insert material	15,000	0.30	0.95	[32]

*Experimentally determined

Figures

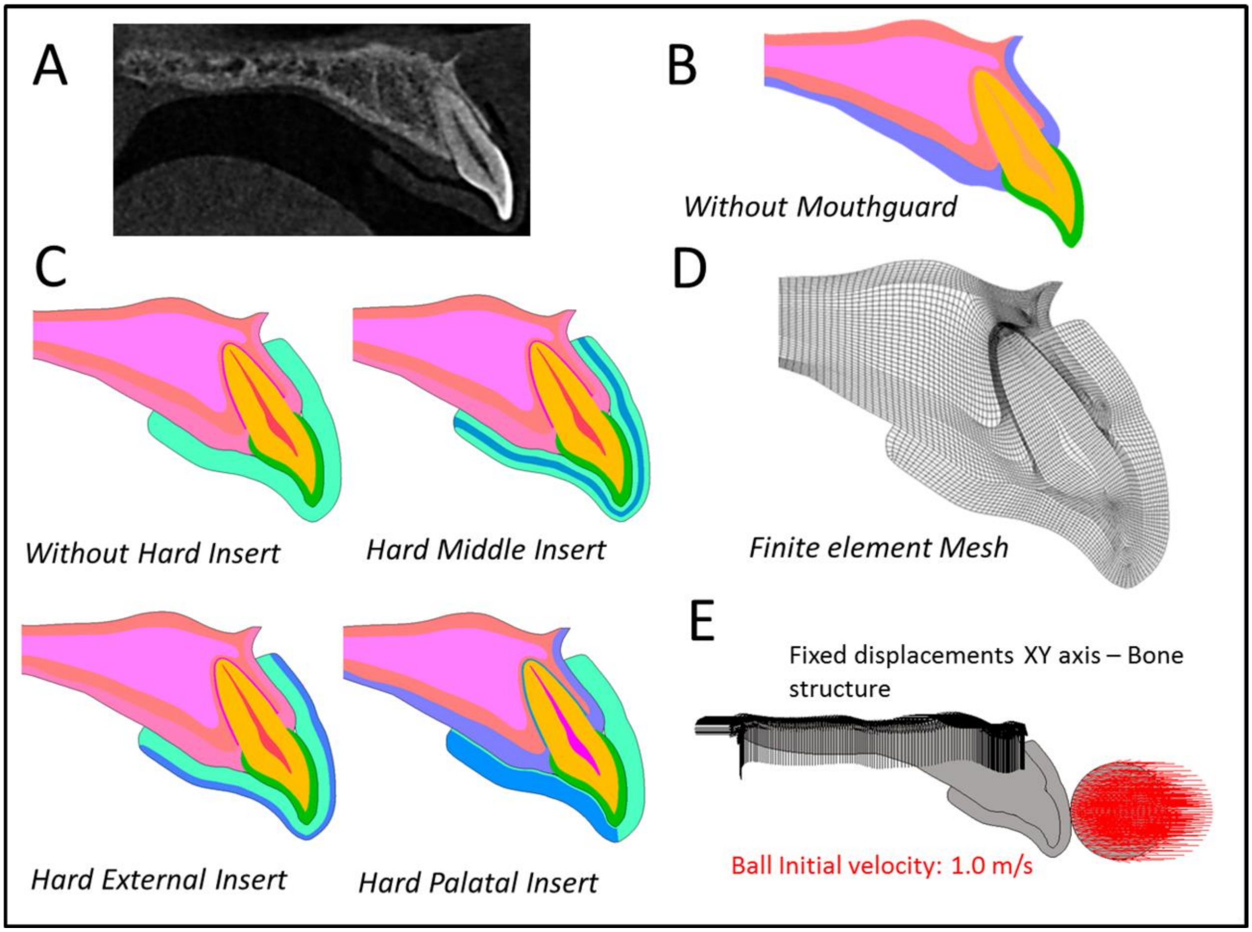

Figure 1. Generation of two-dimensional finite element models. A) CT-tomography image of maxillary central incisor with a mouthguard; B) Model created without mouthguard; C) Mouthguard models created: EVA mouthguard without hard insert (uniform elastic modulus), hard middle, external, and palatal inserts; D) Finite element mesh (with a 3 mm thick mouthguard); E) Initial boundary conditions.

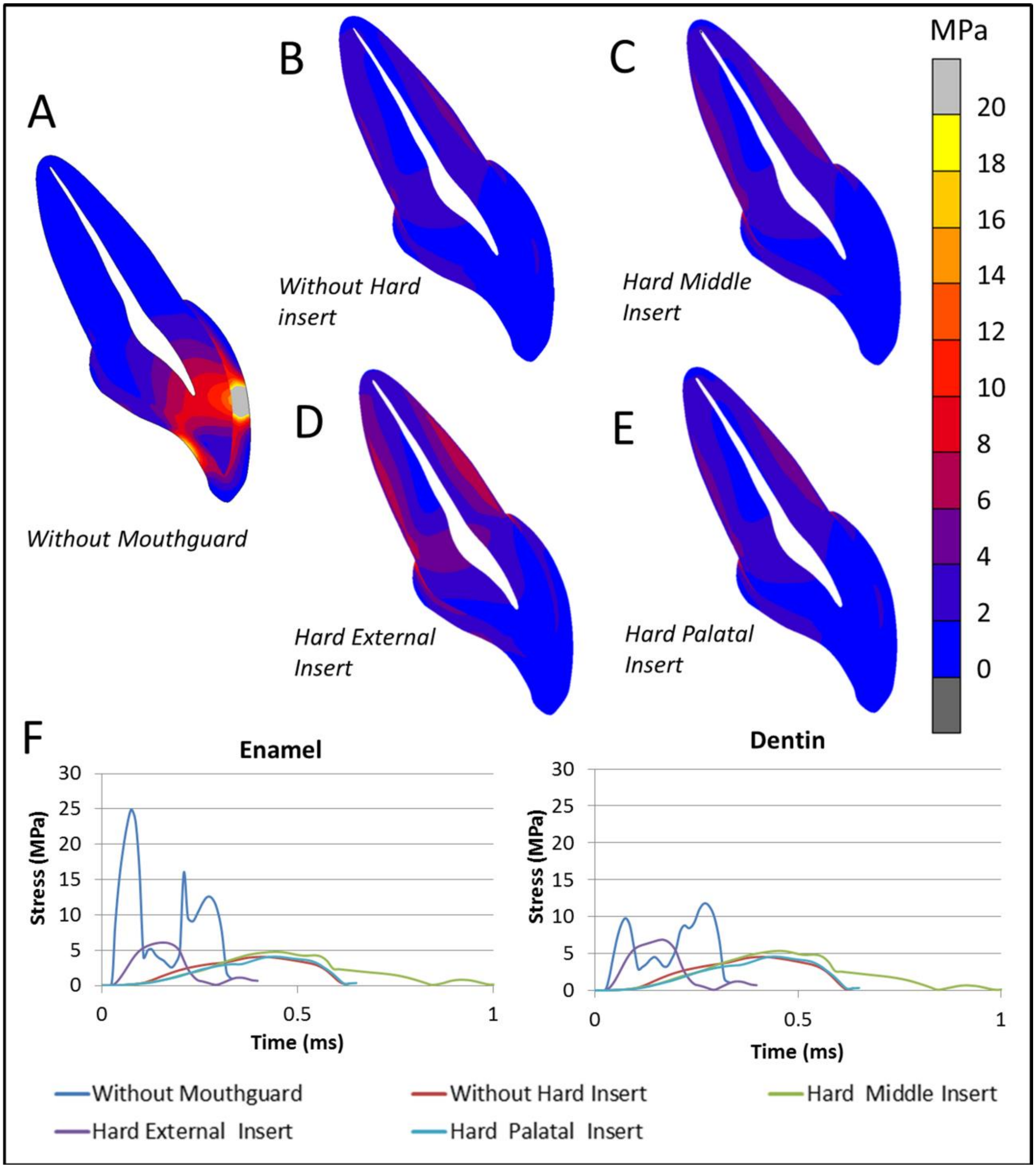

Figure 2. Von Mises stress distributions at the peak of impact. A) Without mouthguard; B) Mouthguard without insert; C) Hard middle insert; D) Hard external insert; E) Hard palatal insert; F) Mean of 10% highest stress values for enamel and dentin during the impact.

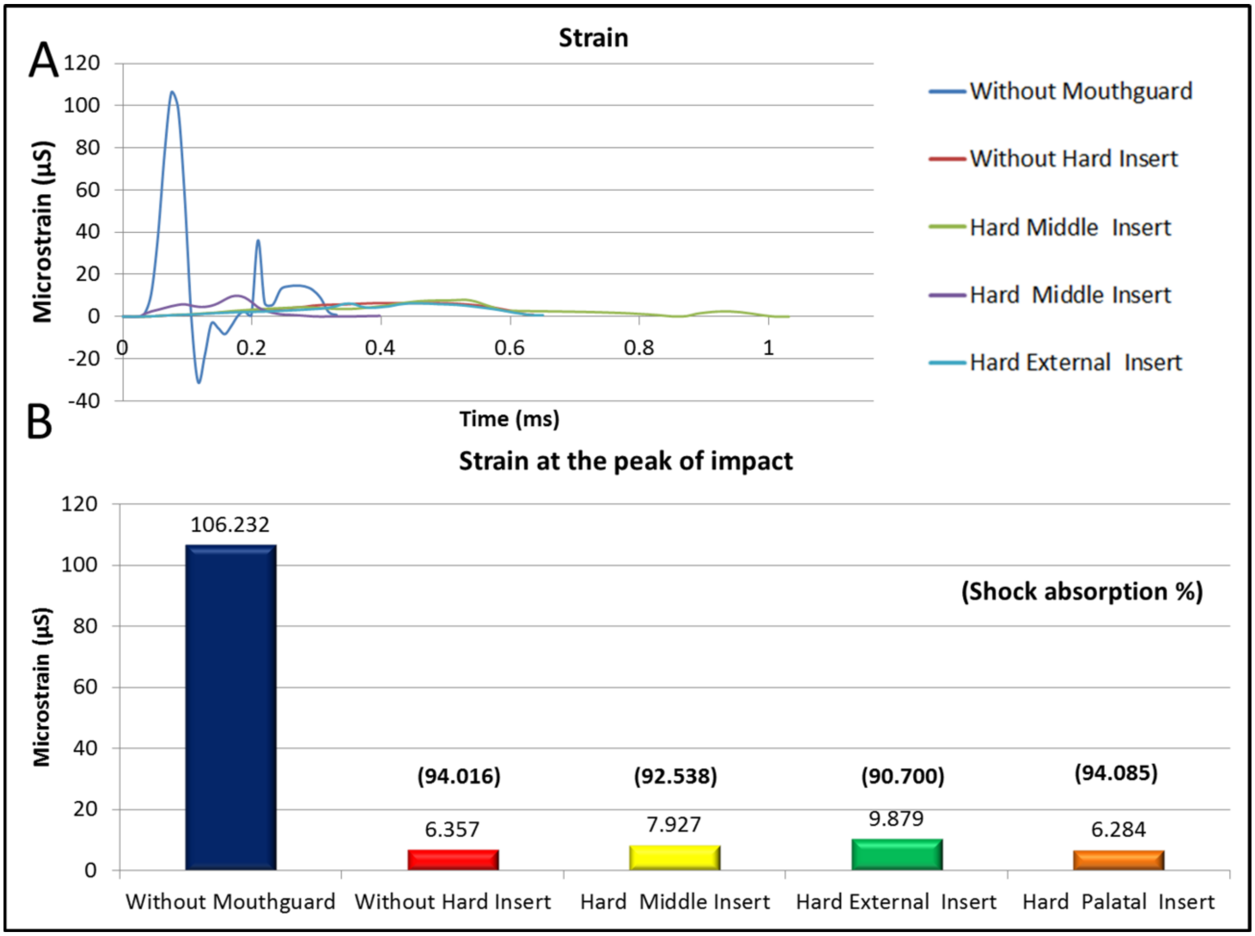

Figure 3. Strain values at the palatal side of the tooth crown. A) History plot during the impact; B) Microstrain values at the peak of impact and percentage shock absorption in parentheses.

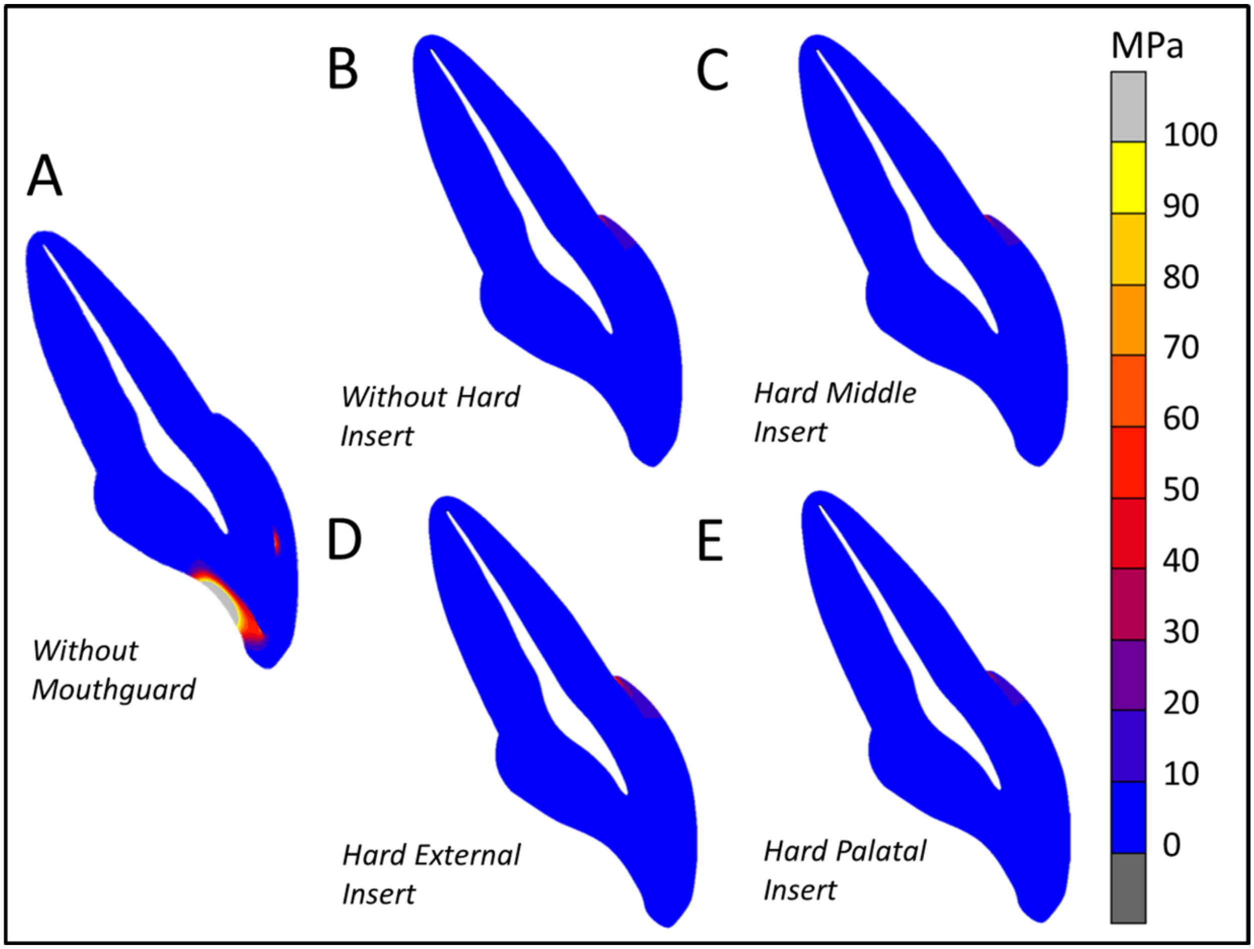

Figure 4. Critical modified von Mises stress distributions at the peak of impact. A) Without mouthguard; B) Mouthguard without insert (solid EVA); C) Hard middle insert; D) Hard external insert; E) Hard palatal insert.

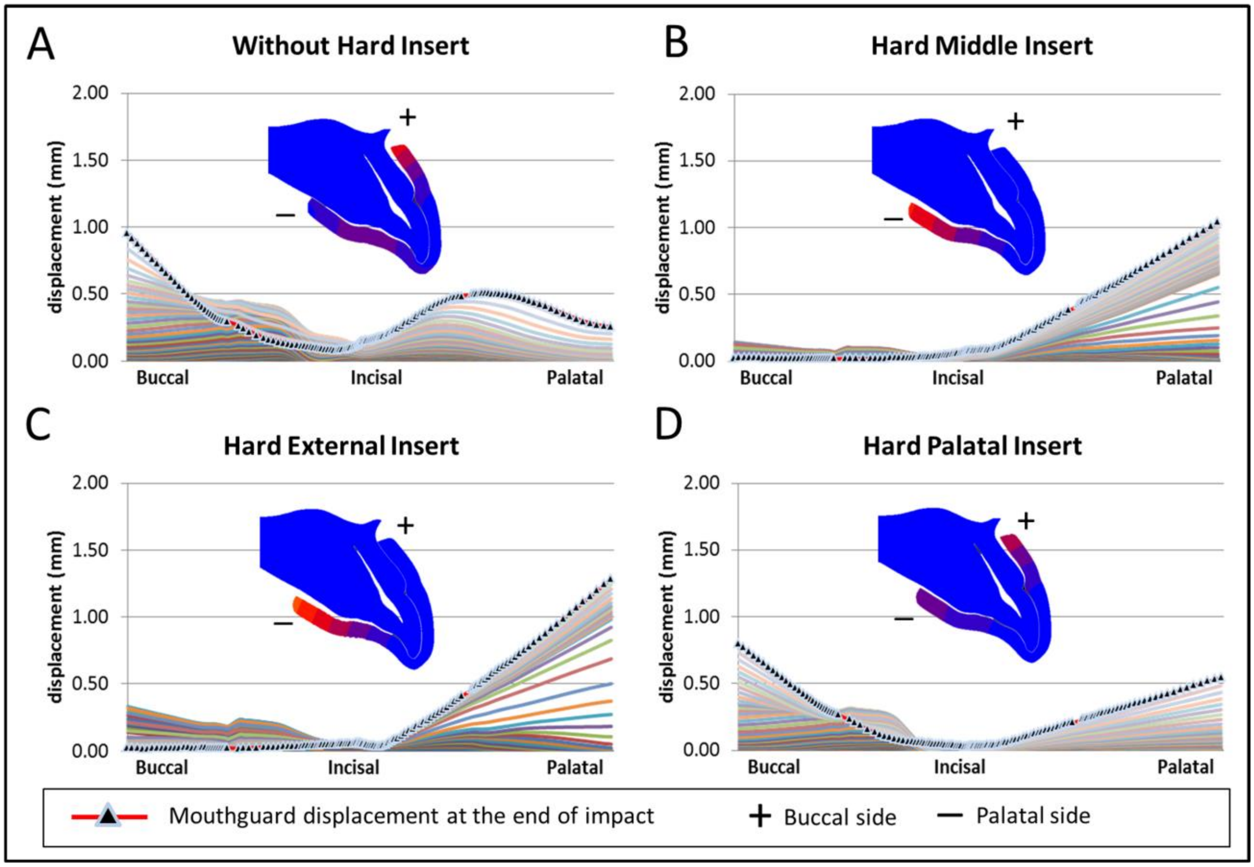

Figure 5. Path plot of the mouthguard displacement (mm) during the impact application. Blue colors in the tooth model show low displacement values; orange and red are the higher displacement values.

CAPÍTULOS

3.4 CAPÍTULO 4

Can the antagonist tooth contact influence the biomechanical response of mouthguards during an impact?

Artigo a ser enviado para publicação no periódico Dental Traumatology

Title: Can the antagonist tooth contact influence the biomechanical response of mouthguards during an impact?

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Abstract

Background/Aim: The purpose of this non-linear finite element impact study was to evaluate the influence of the antagonist contact on the internal stresses and strains of the tooth-bone complex, shock absorption, and displacement of EVA mouthguards during a horizontal impact. **Material and Methods:** Finite element models of human maxillary central incisor with and without mouthguard with different occlusion conditions (With and without antagonist contact) were created based on a cross-sectional CT-tomography. A non-linear dynamic impact analysis using the Single-Step Houbolt method was performed in which a rigid object hit the model at 1 m/s. Strain and stress (von Mises and Critical modified von Mises) distributions and shock absorption during impact were calculated as well as the mouthguard displacement. **Results:** The model without mouthguard and without antagonist contact showed the highest stress values at the enamel and dentin structures in the tooth crown during the impact compared to the model without mouthguard and with antagonist contact. Mouthguard presence reduced the stress and strain values regardless the occlusion condition. The antagonist contact promoted lower displacements of the mouthguard during the impact. **Conclusions:** Mouthguards are efficient to decrease the stress and strain values on the tooth in front of an impact reaching more than 90% of shock absorption. A mouthguard with balanced occlusion and maximum number of contacts with the mandibular anterior tooth should be considered taking in account the lower displacements observed.

Key words: mouthguard; stress, strain, finite element analysis.

Introduction

It has been reported that sports practice carries a considerable risk of dental and facial injuries (1-3). Mouthguards are devices used by professional players in order to prevent oral and dental injuries (4-6). Several types of injuries can occur in front of an impact and the mechanical behavior of mouthguards is influenced by several factors such as: mouthguard thickness, material and type (Custom-fitted, boil-and-bite and pre-fabricated), impact direction, fit and stability (5, 7). Maxillary central incisors are the most affected by the direct impact mainly because of their position in the dental arch (8, 9). Some studies reported that the support of the maxillary teeth dentitions and the alveolar bones by the mandibular dentition against the mouthguard can positive influence the mechanical response of mouthguards (10). This effect can be achieved when the mouthguards are adjusted in a balanced occlusion. Theoretically, this effect suggest that the mouthguard can exhibit less displacements in front of a sudden impact and decrease the stress and strain over the tooth-bone complex (10). Therefore, the influence of the antagonist contact and the adjusted mouthguard in balanced occlusion on the stress, strain and shock absorption ability of mouthguards is still unclear.

The aim of this study was to evaluate the influence of the antagonist contact on the internal stresses and strains, shock absorption, and displacement of EVA custom-fitted mouthguards during a horizontal impact. The study was carried out using non-linear finite element impact analysis simulating impact on a human maxillary central incisor model in different occlusion conditions (With and without antagonist contact).

Materials and Methods

Two-dimensional Finite Element Impact Analysis

Two-dimensional (2D) geometrical models of a maxillary and mandibular human central incisors in occlusion contact, periodontal ligament, bone support (cortical and trabecular bone), soft tissue, were created based on a cross-sectional CT-tomography image of a patient with normal occlusion without and with a 3mm custom-fitted mouthguard placed in position (Fig. 1A and 1B). Coordinates of the tissue outlines were traced in two dimensions with an image processing and analysis software (Image J, public domain, National Institute of Health, Bethesda, MD, USA) and imported in a finite element analysis program (Marc/Mentat, MSC software, Santa Ana, CA, USA). Cubic-spline curves were created through these coordinates to recreate the tissue outlines. Four models were generated following the occlusion contact conditions: 1- Models without mouthguard (with and without antagonist contact) (Fig. 1C and 1D); and 2- Models with mouthguard (with and without antagonist contact) (Fig. 1E and 1F). The two-dimensional finite element mesh was manually created using four-node isoparametric arbitrary quadrilateral plane strain elements with reduced integration (one integration point per element), which was element type number 115 in the Marc/Mentat software (Fig.1G).

Frictionless contact was prescribed between the mouthguard and the model interface, allowing separation between them during the impact. All other interfaces were not allowed to separate. A dynamic impact analysis was performed using the Single-Step Houbolt method for implicit dynamic contact analysis.(11) A rigid impact object, which was given the properties of steel, was simulated with a 1.0 m/s initial velocity in the x-direction (horizontal) (Fig. 1H). The impact object was unrestrained in its path after this initial velocity was applied. No gravitational or air-friction forces were modeled, thus the path and of the impact object was determined by its inertia and the contact response of the impacted model with or without mouthguard. The nodes on the base of the maxillary and mandibular bone structure were rigidly fixed in the x- and y-directions (Fig 1H). All materials were considered linear, isotropic and homogeneous. The mechanical properties expressed by the elastic modulus, Poisson's ratio and material density are shown in Table 1. The elastic modulus of the ethylene vinyl acetate (EVA) had been experimentally determined from stress-strain curves in tensile tests.

Each model was solved in Marc (MSC software). The impact response was recorded until the impact object lost contact when it bounced back of the mouthguard or tooth structure (models without mouthguard). During the analysis, a fortran-based subroutine recorded the strain values in the y-direction (vertical) for one node at the palatal side of the maxillary central incisor crown to calculate the shock absorption, the stresses in enamel and dentin, and the model displacements. Shock absorption was defined as the percentage of the peak strain of the model without mouthguard. While recording the stresses, the subroutine determined the average value of the 10% highest von Mises equivalent stresses during the impact and calculated the Critical modified von Mises stresses as well. Von Mises stresses were used as an indication for the stress energy, whereas Critical modified von Mises stresses identified critical areas for structural failure due to the impact loads. Unlike von Mises stresses, the Critical modified von Mises stress takes the difference between compressive and tensile strengths into account and scales the resulting equivalent stress value in each material relative to its tensile strength. The compressive strengths were 384.0 and 297.0 MPa for enamel and dentin, respectively, and the tensile strengths 10.3 and 98.7 MPa.(12) The model displacements were used to monitor the mouthguard displacement with respect to the tooth. The distances between the mouthguard and tooth along their interfaces during the impact were calculated using: $d = \sqrt{\{ (x2 - x1)^2 + (y2 - y1)^2\}}$, where, where d is the mouthguard displacement away from the tooth, x_1 and y_1 are the x- and y-coordinates of the node at the tooth surface, and x_2 and y_2 are the coordinates of a corresponding node on the mouthguard surface.

Results

Von Mises stress distributions in the models at the peak of the impact force are shown in Figure 2. The stress values are visualized using a linear color scale in which blue indicates the lowest stress values, and yellow and light gray the highest values. The mean of the 10% highest stresses for enamel and dentin during the impact are shown in Figure 3A and 3B, respectively. The model without mouthguard and without antagonist contact (Fig 2A) had the highest stress values at the enamel and dentin structures in the tooth crown during the impact (Fig. 3A and 3B). A smaller difference in the stress values and distributions at enamel and dentin structure was found between the models without mouthguard taking in account the antagonist contact. For the mouthguard models the location of the stress concentrations changed to the root regardless the antagonist contact condition (Fig. 2C and 2D), and maximum stresses in the enamel and dentin were lower than in the models without mouthguard.

The history plot for the strain values at the palatal side of the tooth and the strain peak values are shown in the Figure 3C. The model without mouthguard and without antagonist contact showed a slight higher value compared with the model without mouthguard and with antagonist contact. The history plot showed that the time to reach the peak strain was longer with the mouthguard. This time is slight lower for the model with mouthguard and antagonist contact. Based on the strain values at the peak of the impact, the shock absorption values calculated for the mouthguard models were 93.77% and 94.24% without antagonist contact and with antagonist contact, respectively.

The distribution of the Critical modified von Mises stresses showed that for the models without mouthguard the critical area for failure at impact was at the palatal side of crown (Fig. 4A and 4B). The path plot of the mouthguard displacement for each model is shown in Figure 5. The contact with the antagonist tooth decreased the mouthguard displacement on the buccal side at the end of the impact.

Discussion

Several factors can influence the mechanical performance of mouthguards such as thickness, occlusion, and mouthguard material (1, 13, 14). Experimental impact tests based on pendulum devices are most often used to evaluate mouthguard performance (4, 15, 16). Although these experiments offer valuable information, they cannot provide details about the internal behavior of materials, such as the stress distributions in the tooth-bone complex in front of an impact. Several studies have been done with mouthguards, however, only a few researchers evaluated the influence of the antagonist contact on the mechanical behavior of mouthguards (10). Their results suggest that mouthguards adjusted in a fully balanced occlusion can improve their function. This observations were made by Takeda et al. 2008 (10) who reported that the influence of anterior occlusion of mouthguards or the mandibular teeth support through the mouthguard is indispensable in reducing the impact force and tooth distortion.

Finite element analysis may be the only method that can predict stress and strain behavior of the materials and structures during impact load. This numerical method incorporates structural design to calculate stress and strain responses by solving the relevant physical equations in a computational analysis. This study used a non-linear dynamic finite element impact analysis to evaluate the stress distributions and strains assuming a plane strain condition in the structures. This engineering term identifies a three-dimensional stress condition that may occur in structures where the strain perpendicular to the cross-sectional plane is zero (12). Dynamic analyses are different from more common static analyses because at high loading rates the inertia forces cannot be neglected. In the current dynamic analysis, the impact object's velocity and inertia were the initial conditions that determined the time-dependent forces to which the tooth and mouthguard models were subjected. Besides the dynamics, the interface between the impact object, mouthguard, and tooth are also important for a realistic impact response. In most of the previously published finite element analyses the tooth and mouthguard elements shared the same nodes at their interfaces, which means that they were perfectly bonded. However, in reality mouthguards are not bonded to the tooth surface or the soft tissues. The current study applied non-linear contact analysis between the impact object, mouthguard and tooth model to predict their interactions and displacements more accurately during the impact.

The results of the finite element analysis showed that the mouthguards reduced maximum stress and strain values in both enamel and dentin regardless the occlusion condition (With or without antagonist contact) (Fig 3). The EVA material of the mouthguards absorbed most of the impact deformation, which increased the time to absorb and redistribute the impact forces and thus decreased the stress and strain on the tooth structure. The presence of a mouthguard therefore allowed the stresses caused by the impact to be distributed through the dentin structures into the bone, which resulted in lower strain values at the palatal side of the crown regardless the occlusion condition (Fig 3C). The finite element analysis also showed that there is a small influence of the antagonist tooth in front an impact without the using mouthguards. The results showed that the model with antagonist contact and without mouthguard is related with slight lower stress and strain values. This can be explained because parts of the stresses are also transferred for the mandibular tooth during the impact contact. In this case, the mandibular tooth can also be involved with injuries.

Crown fracture without pulp exposure is the most frequent dental trauma injury.(8) Thus, information related to location and propagation of crown facture is vital for treatment and prevention of dental traumas. In our study, we used the Critical modified von Mises to assess the critical areas for structural failure. We observed that an impact load horizontal to the dentition and without mouthguard created a potentially critical condition for fracture at the palatal side of the tooth crown regardless the antagonist contact (Fig. 4A and 4B). This stress condition implies bending of the crown at impact, causing compression in the enamel on the buccal side and (critical) tension in the enamel at the palatal side. Presence of mouthguard prevented this critical condition.

During the custom-fitted mouthguard manufacturing process, most of the time an appropriate occlusion with sufficient anterior tooth contact cannot be done in all clinical cases because of the different occlusion patterns (accentuate overbite, different tooth positions, etc.). Our results suggest that an antagonist contact with the mouthguard decrease the mouthguard displacement in front an impact (Fig. 5). The mouthguard displacement is a very important parameter for the impact absorption since a mouthguard should stay in position during function. However, further investigations using three-dimensional finite element modeling of a fully occlusion balanced mouthguard also including the posterior contact should be done in order to reinforce this observations. Despite of there is no significant difference in the stress and strain patterns and shock absorption ability (93.77% and 94.24%) observed between the mouthguard models in different occlusion conditions, a mouthguard with balanced occlusion and maximum number of contacts with the mandibular anterior tooth should be considered taking in account this lower displacements observed. In conclusion, the effects of the mouthguard can be more beneficially, wearing a mouthguard with support by lower dentition through the mouthguard.

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Tables

Table 1. Mechanical properties applied for the dental structures and materials.

Structure	Elastic Modulus (MPa)	Poisson's ratio	Density (g/cm^3)	References
Enamel	84,100	0.30	2.14	(17)
Dentin	18,600	0.30	2.97	(18)
Periodontal ligament	50	0.45	0.95	(19)
Trabecular bone	1,400	0.31	0.70	(20)
Cortical bone	13,700	0.33	2.00	(20)
Soft tissue	1.8	0.30	0.95	(21)
Steel	200,000	0.30	7.8	(22)
EVA	18.075*	0.30	0.95	(23)

*Experimentally determined in this study

Figure legends

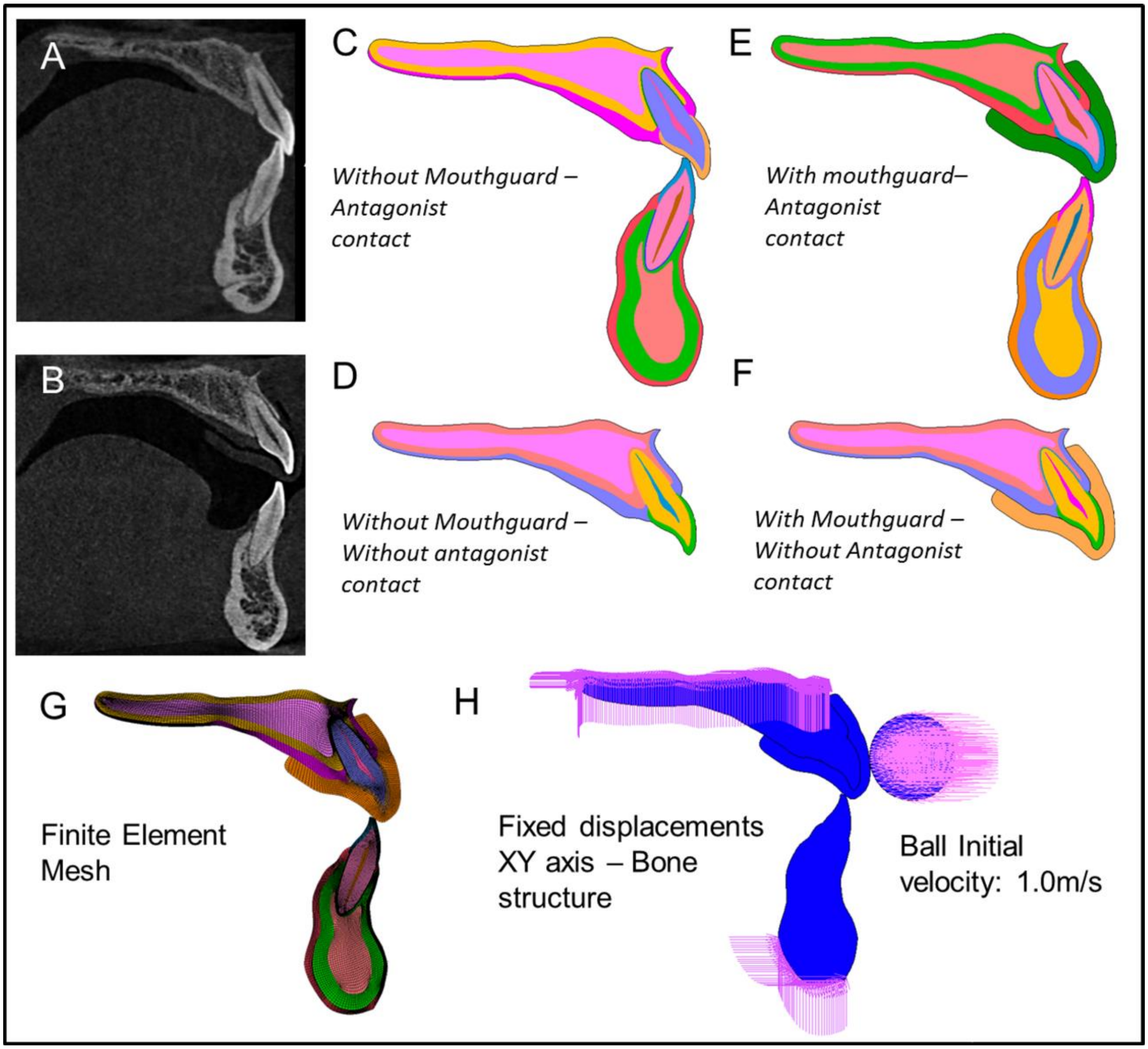

Figure 1. Generation of two-dimensional finite element models. A) CT-tomography image of maxillary central incisor without a mouthguard; B) CT-tomography image of maxillary central incisor with a mouthguard; C) Model created without mouthguard and antagonist contact; D Model created without mouthguard and without antagonist contact; E) Model created with mouthguard and antagonist contact; D Model created

with mouthguard and without antagonist contact; G) Finite element mesh; H) Initial boundary conditions.

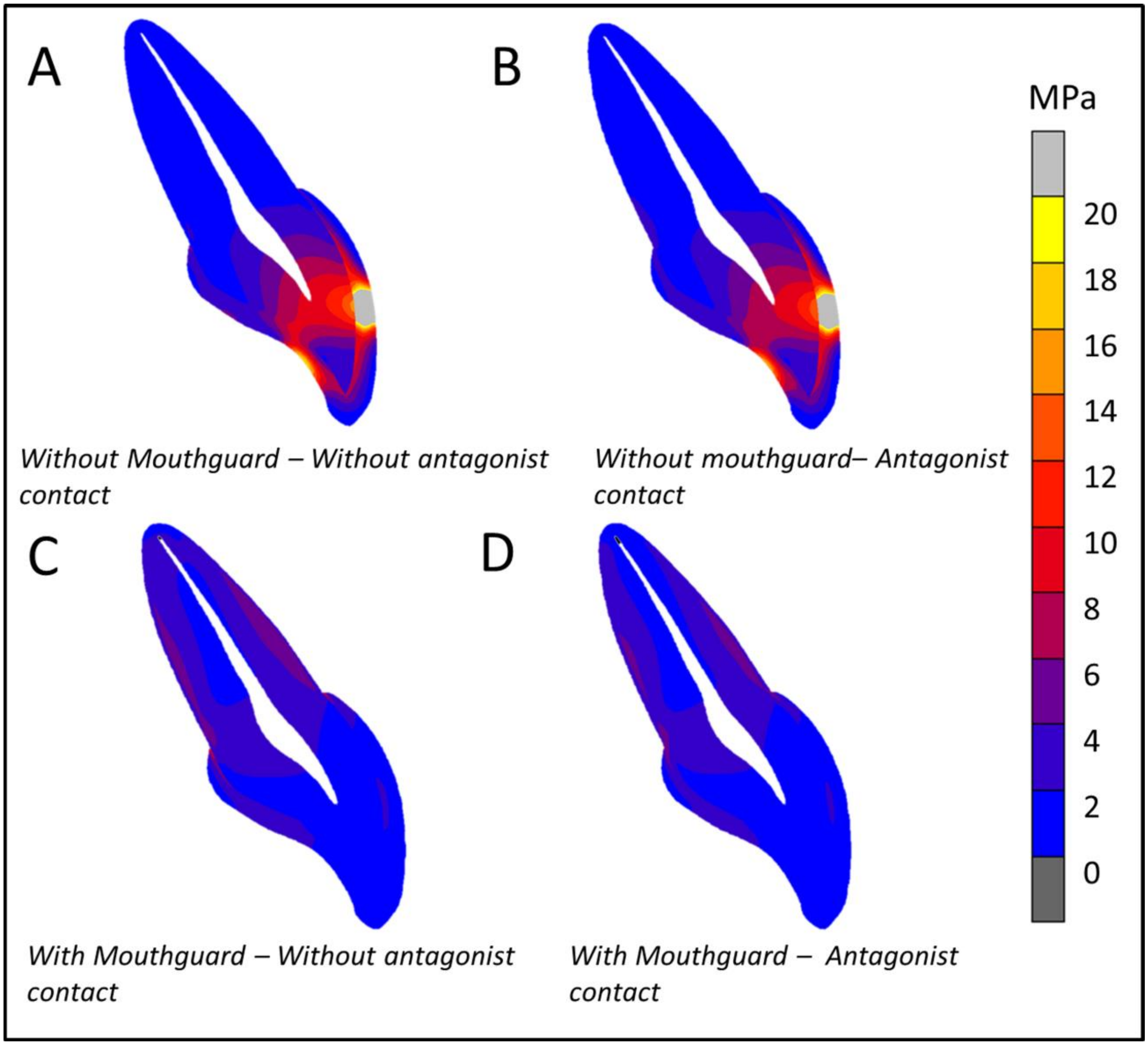

Figure 2. Von Mises stress distributions at the peak of impact A) Without mouthguard and without antagonist contact; B) Without mouthguard and antagonist contact; C) With mouthguard and without antagonist contact; D) With mouthguard and antagonist contact.

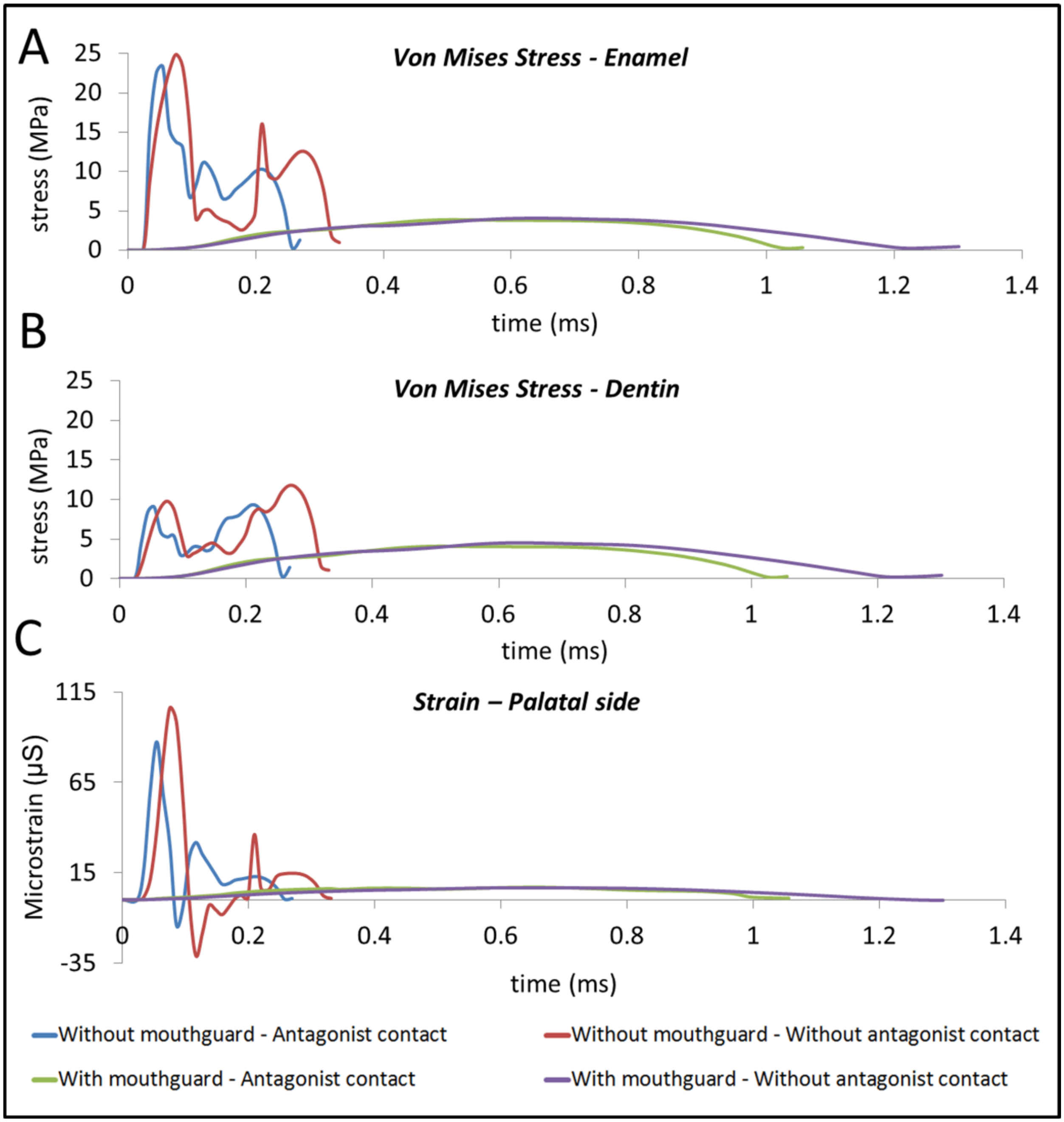

Figure 3. A) Mean of the 10% highest stress values for enamel; B) Mean of the 10% highest stress values for dentin; C) History plot of the strain values at the palatal side of the tooth crown during the impact.

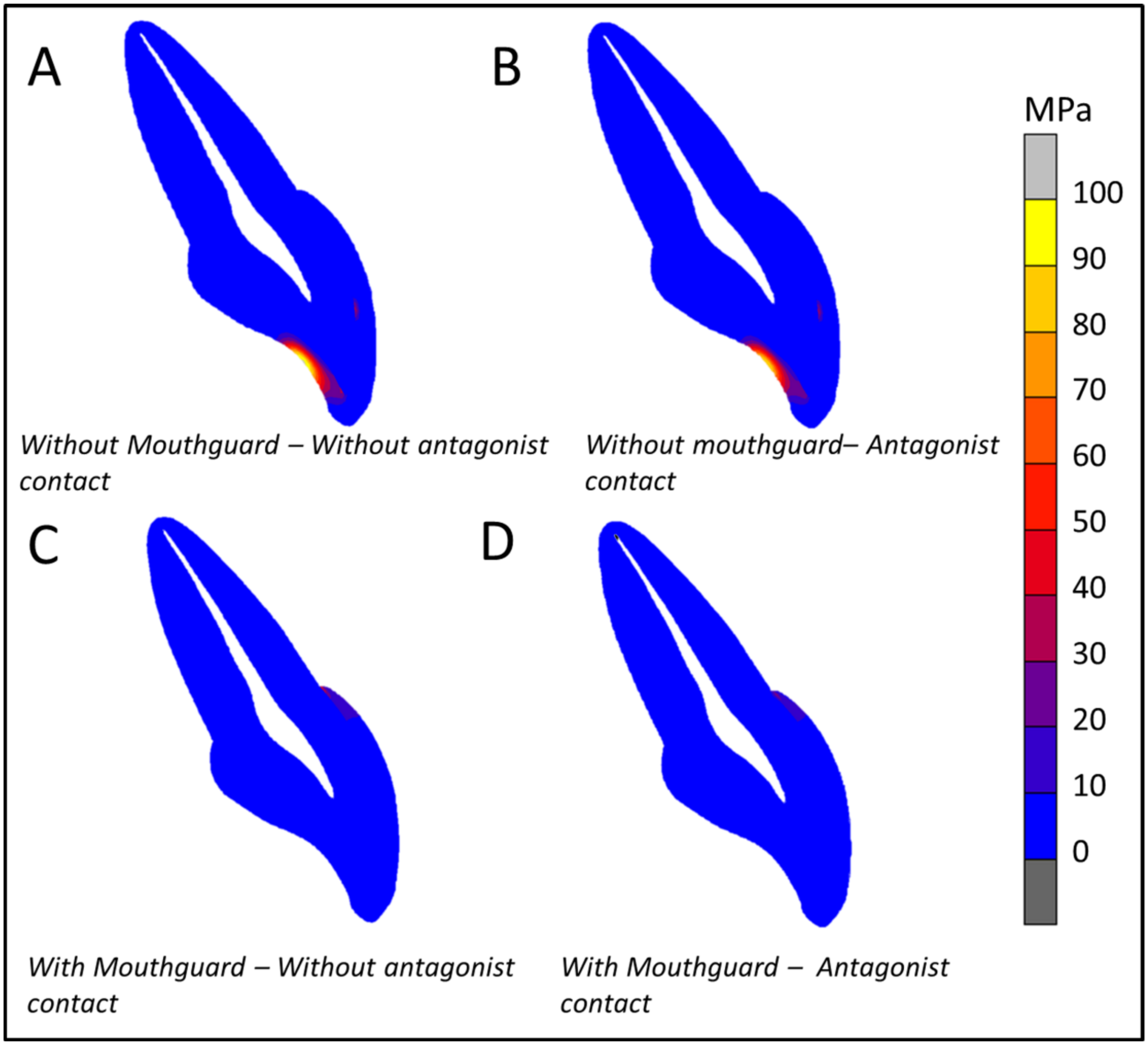

Figure 4. Critical modified von Mises stress distributions at the peak of impact. A) Without mouthguard and without antagonist contact; B) Without mouthguard and antagonist contact; C) With mouthguard and without antagonist contact; D) With mouthguard and antagonist contact

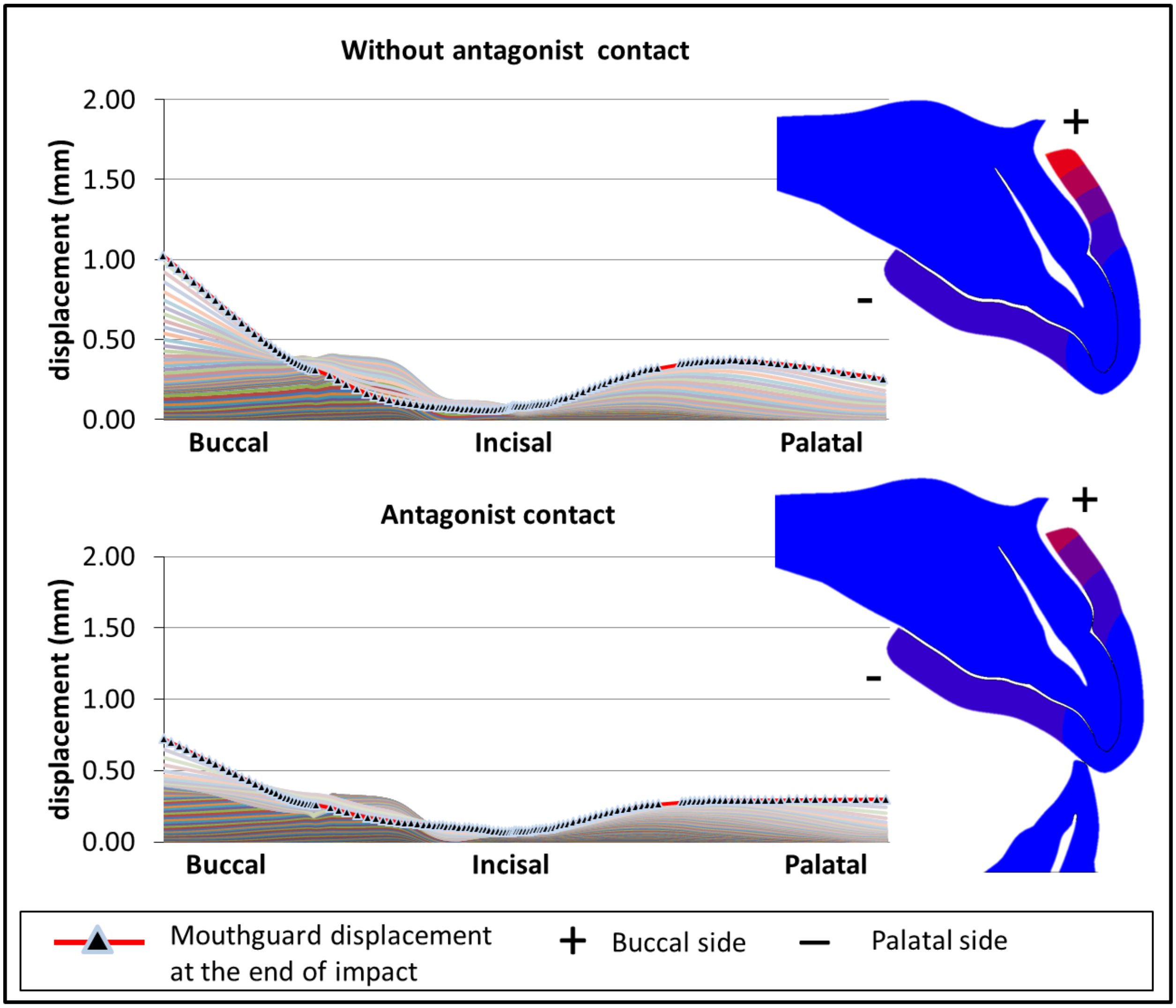

Figure 5. Path plot of the mouthguard displacement (mm) during the impact application. Blue colors in the tooth model show low displacement values; orange and red are the higher displacement values.

CAPÍTULOS

3.5 CAPÍTULO 5

Protetores bucais personalizados: aspectos clínicos e biomecânicos.

Custom-fitted mouthguards: Clinical and biomechanical aspects.

Artigo a ser enviado para publicação no periódico Clínica – International Journal of Brazilian Dentistry

Protetores bucais personalizados: aspectos clínicos e biomecânicos.

Custom-fitted mouthguards: Clinical and biomechanical aspects.

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Resumo

Protetores bucais são dispositivos utilizados com objetivo de absorver as tensões geradas pelo impacto e prevenção de traumatismos dento-alveolares durante prática esportiva. Este artigo apresenta por meio de associação de evidência científica e relato de caso uma abordagem crítica dos parâmetros envolvidos com de confecção de protetor bucal personalisado em etileno vinil acetato (EVA) e funções durante o uso. A associação de ensaios laboratoriais e computacionais como método de elementos finitos são essenciais para entendimento do comportamento biomecânico dos protetores bucais. O presente estudo apresenta evidência científica que comprova a eficiência de protetores bucais personalizados na absorção de choques e prevenção de traumas.

Palavras chaves: Protetores bucais. Tensão. Deformação. Absorção de impactos.

Abstract

Mouthguards are devices used in order to absorb the stresses generated by the impact and prevent of dental trauma during sports practice. This article presents through association of scientific evidence and case report an approach of the critical parameters involved with the Ethylene Vinyl Acetate (EVA) custom-fitted mouthguard manufacturing process and function during use. The associations of laboratory and computational tests as finite element method are essential to understanding the biomechanical behavior of mouthguards. This study presents scientific evidence that proves the efficiency of EVA custom-fitted mouthguards on the shock absorption and preventing dental trauma.

Key-words: Mouthguards. Stress. Strain. Shock Absorption.

SIGNIFICÂNCIA CLÍNICA

Protetores bucais personalizados são capazes de diminuir os níveis de tensões e deformações geradas durante um impacto. Os benefícios da utilização de protetores bucais foram comprovados por diversos estudos da literatura. Os resultados deste estudo demonstram que estes dispositivos são essenciais para prevenção de traumatismos dento-alveolares durante práticas esportivas.

1. Introdução

A prática de esportes de contato está altamente relacionada com a ocorrência de traumatismos dento-alveolares [1-5]. O trauma na região oral pode resultar em diferentes tipos de injúrias envolvendo dentes e tecidos de suporte (osso alveolar e ligamento periodontal). A complexidade dos traumatismos dento-alveolares pode ser aumentada pela combinação entre as luxações e fraturas dentárias [6]. Entretanto, dentre os tipos de traumatismos dento-alveolares, a avulsão dentária, caracterizada pelo completo deslocamento dentário do alvéolo com consequente ruptura do ligamento periodontal apresenta o pior prognóstico de tratamento [6]. A primeira opção de tratamento nos casos de avulsão é o reimplante imediato, porém a manutenção do dente no alvéolo está relacionada a fatores como tempo para o reimplante, soluções de armazenamento e tratamentos realizados após o reimplante (contenções dentárias, etc.) [7, 8]. Neste caso, estudos demonstram que a utilização de água de coco apresenta resultados promissores quando utilizada como meio de armazenamento para dentes avulsionados preservando a viabilidade celular do ligamento periodontal pelo período de 24 horas [8].

Para reduzir os efeitos prejudiciais dos traumas dentários recomenda-se o uso de protetores bucais, que constituem dispositivos utilizados por atletas ou praticantes de esportes de contato na prevenção de traumatismos dento-alveolares. De acordo com Reed,[9] a primeira tentativa de confecção de um dispositivo para proteção de estruturas orais na prática de esportes foi feita no ano de 1890, quando o dentista inglês Wolf Krause utilizou duas camadas de gutta-percha aderidas aos dentes superiores de um praticante de boxe. Atualmente, diversas modificações foram feitas na confecção de protetores bucais e três principais tipos de protetores normatizados pela American Society for Testing materials (ASTM F697-80) podem ser encontrados no mercado: termoplásticos (Boil-and-bite), pré-fabricados (estoque) e personalizados [10]. Atualmente, os protetores bucais personalizados são recomendados pela FDI (Fédération Dentaire Internationale) pois apresentam vantagens como: conforto, adaptação, estabilidade, capacidade fonética e respiratória, além de proporcionar melhor proteção das estruturas dento-alveolares [11].

Os protetores bucais tem a função de distribuir as tensões geradas pelas forças aplicadas diretamente sobre as estruturas faciais e dentárias, e absorver a energia gerada pelo impacto [1, 3, 12]. Além dessa função, os protetores atuam aumentando a distância entre o côndilo e a fossa articular da Articulação temporo-mandibular (ATM) prevenindo o impacto do côndilo com as estruturas adjacentes (fossa articular e base do crânio). Esta característica está relacionada com a diminuição do risco de concussões cerebrais [3, 13].

Dentro das incontáveis perguntas que permeiam a realidade do profissional frente à procedimentos de seleção e confecção de protetores bucais a busca por evidências científicas que tragam ao clínico maior segurança é imperativo para o sucesso profissional e dos procedimentos realizados. Portanto este trabalho tem por objetivo apresentar a associação entre dados relevantes de pesquisas laboratoriais, ensaios computacionais com relato de caso descrevendo etapas clínicas necessárias para a confecção de protetor bucal personalizado empregado para a prevenção do traumatismo dento-alveolar.

2. Relato de caso clínico

2.1. Etapas clínicas necessárias para confecção de protetor bucal personalizado

Paciente de 21 anos, gênero masculino, compareceu a Clínica de Traumatismo Dento-Alveolar da Faculdade de Odontologia da Universidade Federal de Uberlândia (FOUFU), buscando pela confecção de protetor bucal para ser utilizado na prática esportiva. Durante a anamnese o paciente relatou a ocorrência de traumas na região da face devido à pratica de artes marciais, porém sem ocorrência de danos severos. Preocupado com a ocorrência de novos traumas na face, o mesmo procurou a Clínica de Traumatismo Dento-Alveolar do Hospital Odontológico da UFU que é centro de referência regional em odontologia para traumas dento-alveolares e prevenção com utilização de protetores bucais. Durante exame clínico notou-se satisfatória qualidade de higienização e ausência de processos cariosos e infecciosos. Diante das informações colhidas durante a anamnese e exame clínico foi proposto para o paciente confecção de protetor bucal personalizado.

Inicialmente, foi realizada profilaxia dos dentes superiores e inferiores empregando pedra pomes e solução de clorexidina 0.12% seguida da seleção das moldeiras de estoque para procedimento de moldagem com alginato. As moldeiras de estoque selecionadas foram individualizadas empregando cera utilidade com objetivo de moldar as inserções musculares, freios e fundo de saco de vestíbulo. A etapa de moldagem é crítica para a confecção de um protetor bucal personalizado. Durante esta etapa, o clínico deve verificar se a moldagem foi capaz de copiar com fidelidade as estruturas dentárias bem como as inserções musculares (Figura 1). A moldagem das arcadas superior e inferior foi realizada com hidrocolóide irreversível (alginato) (Hydrogum, Zhermack, Badia Polesine, RO, Itália).

Após avaliação e percepção da fiel moldagem dos dentes e mucosa atingindo adequadamente o fundo de saco de vestíbulo os moldes foram desinfectados com hipoclorito de sódio a 1% e os modelos foram confeccionados com gesso especial tipo IV (Durone IV, Dentsply, Petrópolis, RJ, Brasil) (Figura 2). Foi então realizada abertura na região central do palato do modelo de gesso com forma circular e diâmetro de aproximadamente 10mm com broca Maxicut (Edenta AG, Hauptstrasse, Switzerland) para facilitar a ação do vácuo durante a moldagem com o EVA melhorando assim a prensagem da placa e obtenção de detalhes da superfície do modelo de gesso (Figura 3 e 4).

Em seguida, foram selecionadas duas placas de EVA na espessura de 3 mm (Bio-art EVA sheets, São Carlos, SP, Brazil) para confecção do protetor nas cores verde e transparente. A espessura das placas foi verificada com auxílio de paquímetro digital (Mitutoyo, Tokyo, Japão). O uso de duas placas é necessário tendo em vista que o aquecimento (Figura 5) gerado no processo, a forma da placa, bem como os métodos de plastificaçao e modelagem reduzem a espessura final do protetor bucal em cerca de 1,0mm [14-16]. Com isso atingiu-se a moldagem do modelo com as placas de EVA na espessura final ideal de 4mm [17, 18].

Inicialmente, a placa de coloração verde foi prensada sobre o modelo de gesso após processo de aquecimento em plastificadora a vácuo (Plastivac P7; Bio-art) (Figura 6). Durante esta etapa o aquecimento deve ser promovido até o momento em que a placa de EVA adote forma ovalada e próxima da superfície do modelo. Então a placa de EVA é prensada contra o modelo. Foram feitas marcações na superfície do protetor bucal afim de delimitar a área de recorte do protetor bucal: fundo de saco de vestíbulo e extensão palatina de 10mm da margem gengival (Figura 7). A placa foi removida do modelo de trabalho e o recorte inicial feito com auxílio de uma tesoura reta seguindo a área delimitada pelas marcações iniciais. (Figura 8). Feito o recorte inicial, foi verificada adaptação ao modelo e os excessos removidos com broca Maxicut montada em peça-reta em baixa rotação (Figura 9). O recorte do protetor bucal na região vestibular deve respeitar as áreas de inserções musculares. Este procedimento visa diminuição do deslocamento do protetor por ação dos músculos da mastigação e da face.

Após a plastificação e remoção dos excessos da primeira placa, foi realizado novo processo de aquecimento e prensagem da segunda placa, neste caso transparente (Figura 10). Após o resfriamento da segunda placa de EVA os excessos foram removidos como descrito anteriormente (Figura 11). Realizou-se o acabamento nas superfícies de recorte com pontas de acabamento (Figura 12) e de polimento Exacerapol (Edenta AG, Switzerland) com objetivo de refinamento das extremidades do protetor bucal para remoção de áreas que porventura gerassem desconforto ao paciente (Figura 13). Por fim, a superfície de recorte previamente polida foi levemente plastificada com lamparina Hannau a fim de melhorar a textura de superfície (Figura 14).

Após confecção do protetor bucal, os modelos de gesso do paciente foram montados em articulador semi ajustável (BioArt, Brasil) para ajuste e distribuição dos contatos oclusais (Figura 15). Com os modelos montados no articulador, utilizando-se lamparina Hannau plastificou-se a região correspondente a oclusal dos dentes no protetor com objetivo de marcar os contatos dos dentes antagonistas no protetor bucal personalizado. Dessa forma, maior estabilidade é obtida, proporcionando ao paciente maior conforto durante o uso. O ajuste do protetor bucal também é importante pois o contato do protetor com os dentes antagonistas diminui o deslocamento do protetor bucal durante o impacto (Figura 15). Após o ajuste, a espessura final de 4mm do protetor bucal foi verificada com auxílio de paquímetro digital. O clínico também pode lançar mão de um especímetro para verificação da espessura final. Neste ponto da técnica o clínico deve atentar-se com a espessura do protetor pois o aquecimento demasiado durante o ajuste pode diminuir a espessura do mesmo na região oclusal.

Realizadas as etapas laboratoriais, o protetor bucal personalizado finalizado (Figura 16) foi posicionado na boca do paciente, e prosseguiu-se para a verificação da adaptação, estabilidade e conforto do paciente durante seu uso (Figura 17). Foi recomendado ao paciente a higienização periódica do protetor bucal com Digluconato de Clorexidina a 0.2%. Ademais o paciente foi orientado sobre a verificação periódica do protetor bucal buscando avaliar o desgaste de superfície e alterações na adaptação.

Por fim o paciente também foi orientado sobre as consequências de um impacto oro-facial sem utilização de protetores bucais (Figura 18) e como as tensões geradas pelo impacto são distribuídas para o ligamento periodontal e osso alveolar (Figuras 17A e 17B). Estas consequências e mecanismos de absorção de tensões serão discutidas na próxima sessão deste artigo.

3. Discussão

Diferentes polímeros tem sido empregados para a fabricação de protetores bucais tais como: borracha natural, resina acrílica, poliuretano e o cloreto de polivinila [19, 20]. Entretanto o etileno vinil acetato ou copolímero de etileno e acetato de vinila (EVA) com 18-28% de acetato de vinila é o material mais utilizado para a confecção de protetores bucais [21]. A partir de ensaios laboratoriais, nossos estudos demonstraram que o EVA apresenta baixo módulo de elasticidade, em torno de 18.0 MPa, ou seja este material tem como característica intrínseca a alta capacidade de sofrer deformações [22]. Essa característica do EVA é fundamental para eficiente absorção de impactos de protetores bucais e por isso o mesmo deve ser material de escolha para confecção de protetores bucais personalizados conforme utilizado no presente caso clínico. Além disso, o EVA apresenta propriedades físicas que permitem o aquecimento e maleabilidade sem perda significativa de propriedades [15].

A capacidade de absorção de impactos fornecida pelo EVA é fator determinante para o mecanismo de funcionamento dos protetores bucais. Resultados de análise de impacto por elementos finitos demonstram que os protetores bucais reduzem os valores máximos de tensão e deformação nas estruturas dentárias (Esmalte e dentina coronária e radicular) (Figura 17). O protetor bucal além de aumentar a superfície de contato do objeto de impacto com a estrutura coronária, absorve a energia gerada pelo impacto e aumenta o tempo de resposta do complexo dento-alveolar frente ao impacto. Dessa maneira, as tensões são distribuídas para a dentina radicular e consequentemente para as estruturas de suporte em níveis abaixo da resistência máxima à tração e compressão do esmalte e dentina (Figura 17A). Ou seja, dentro dos limites de resistência dos mesmos. Por outro lado, na ausência do protetor bucal, elevados níveis de tensões são geradas em curto espaço de tempo, consequentemente as mesmas apresentam-se concentradas em alta intensidade na estrutura coronária (Figura 17B). Esta concentração excessiva de tensões pode levar a fratura dental ou então a avulsão dental.

Utilizando critério que leva consideração os valores de resistência máxima à compressão e à tração, podemos avaliar em escala visual de cores quais são os locais passíveis de fraturas dentárias. Frente a um impacto horizontal, o esmalte sofre alta compressão na região vestibular em consequência do contato com o objeto de impacto gerando abrupta flexão da coroa dentária. Esse fenômeno gera elevados níveis de tensões de tração na região palatina criando uma condição crítica para ocorrência de fraturas coronárias (Figura 19). Entretanto esta condição crítica de fratura é eliminada com a utilização de protetores bucais tornando-os dispositivos essenciais para prevenção de traumas dentários.

A capacidade de absorção de impacto está diretamente relacionada com a espessura final do mesmo. Isso significa que quanto mais espesso for o protetor bucal maior é a capacidade de absorção de impactos. A espessura final pode ser influenciada pelo processo de aquecimento e moldagem da placa de EVA durante a confecção resultando em diminuição da espessura final desejada [14-16]. Conforme apresentado no relato de caso clínico acima, a união de duas placas de EVA de 3mm para confecção do protetor bucal resulta em espessura final de 4mm. A utilização de apenas uma placa de EVA de 3mm resulta em protetores com espessura insuficiente, diminuindo a capacidade de absorção de impactos. O equilíbrio entre a espessura protetor bucal e seu conforto é fundamental para o desempenho físico e aceitação do atleta durante à prática esportiva. Protetores bucais espessos são passíveis de causar desconforto e problemas respiratórios, diminuindo a performance atlética dos usuários. Além disso, eles podem comprometer a proteção natural promovida pelos lábios e bochechas e não permitir o selamento labial, aumentando o risco de lesões dos tecidos moles. Dessa forma, protetores bucais personalizados devem apresentar espessura de 4 mm.

Segundo Takeda et al. em 2008 [23], o ajuste oclusal do protetor bucal e a obtenção do maior número de contatos oclusais reflete em melhor absorção de impacto. A análise computacional por elementos finitos desenvolvida pelo nosso grupo demonstrou que o contato com o dente antagonista influência no padrão de deslocamento do protetor bucal frente a um impacto promovendo menores deslocamentos do mesmo na região anterior como observado na Figura 15. No entanto, o padrão de oclusão do paciente nem sempre permite o ajuste completo do protetor bucal devido a má-oclusões, overjets e overbites acentuados entre outros problemas. A montagem do modelo de confecção em articulador semi-ajustável é essencial para a obtenção do maior número de contatos em função da oclusão do paciente e deve ser considerada em toda confecção de protetores bucais personalizados [23].

A associação entre pesquisa e aplicação clínica é essencial para o sucesso clínico de todo tratamento odontológico. A confecção de protetores bucais personalizados é procedimento simples, de baixo custo e que pode ser realizado no consultório odontológico em apenas duas sessões clínicas. Entretanto, na maioria das vezes fatores críticos que estão envolvidos com sua confecção e uso são negligenciados. O cirurgião-dentista deve sempre questionar sobre o uso de protetores bucais para pacientes praticantes de esportes e com histórico de traumatismos dento-alveolares e propor a confecção e utilização destes dispositivos com referencial teórico aqui apresentado. Dessa forma, o cirugião-dentista, com base na prática clínica baseada em evidências pode contribuir de forma significativa para diminuição da incidência de traumas dento-alveolares.

Conclusões e Orientações ao clínico.

Protetores bucais personalizados são capazes de reduzir as tensões e deformações frente a impactos gerados durante a prática de esportes e devem ser utilizados afim de diminuir a probabilidade de ocorrência de traumatismos dento-alveolares. Além disso, protetores bucais personalizados apresentam vantagens em termos de conforto, estabilidade e adaptação e devem ser considerados com opção principal em relação aos protetores demais tipos de protetores (pré-fabricados e termoplásticos).

Orientações durante a confecção e etapas clínicas:

- Protetores bucais personalizados devem ser confeccionados com espessura final de 4mm. A utilização de duas placas de EVA na espessura de 3mm é suficiente para obtenção da espessura final recomendada de 4mm.
- A espessura do protetor bucal deve ser confirmada em todas as regiões do protetor bucal com auxílio de especímetro.
- O correto recorte do protetor bucal é essencial para a adaptação e conforto durante o uso. O corte deve seguir toda extensão do fundo de saco de vestíbulo na região vestibular e na região palatina respeitar a extensão de 10mm além da margem gengival.
- A montagem dos modelos de trabalho em articulador e ajuste do protetor bucal de acordo com a oclusão do paciente é fundamental para diminuir os deslocamentos do protetor bucal frente ao impacto.
- Por fim, o correto recorte, acabamento e polimento das superfícies de recorte e verificação da adaptação são imprescindíveis para a aceitação e conforto durante o uso.

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Figuras e Legendas

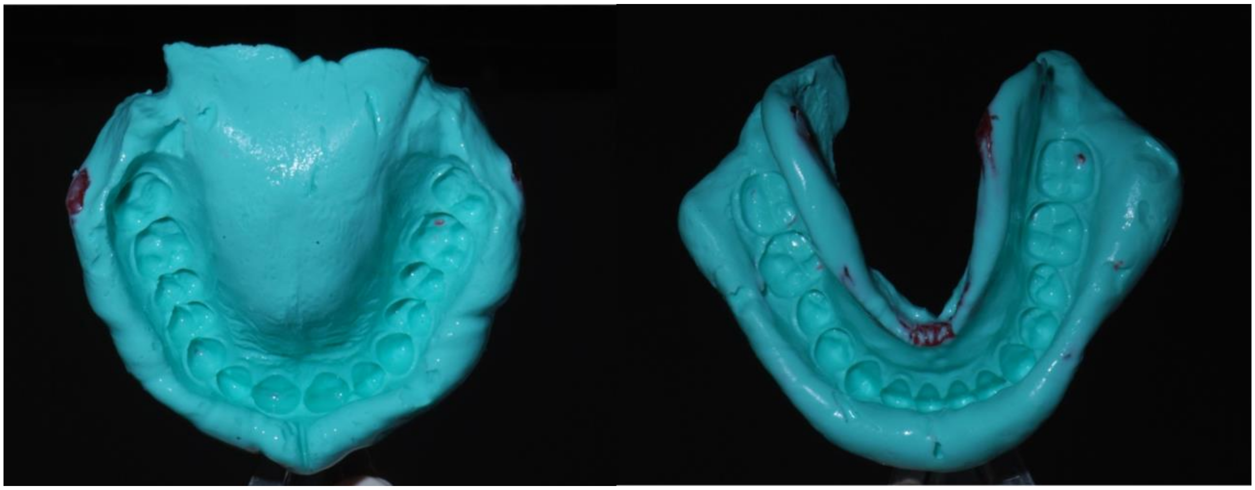

Figura 1. Molde dos arcos superior e inferior. Note que a moldagem foi capaz de copiar as inserções musculares, fundo de vestíbulo e estruturas dentárias.

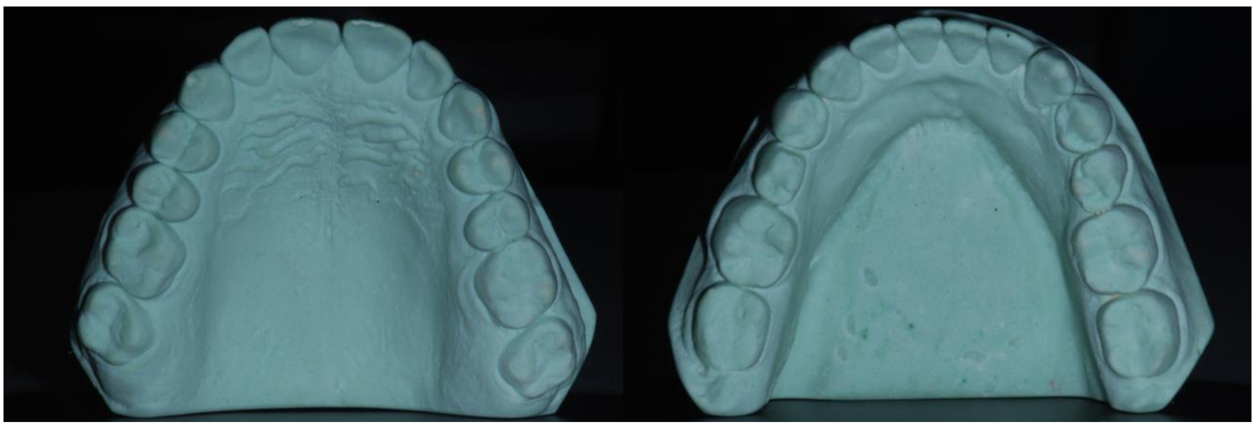

Figura 2. Modelos trabalho superior e inferior confeccionados em gesso especial tipo IV.

Figura 3. Confecção de abertura na região central do palato no modelo superior.

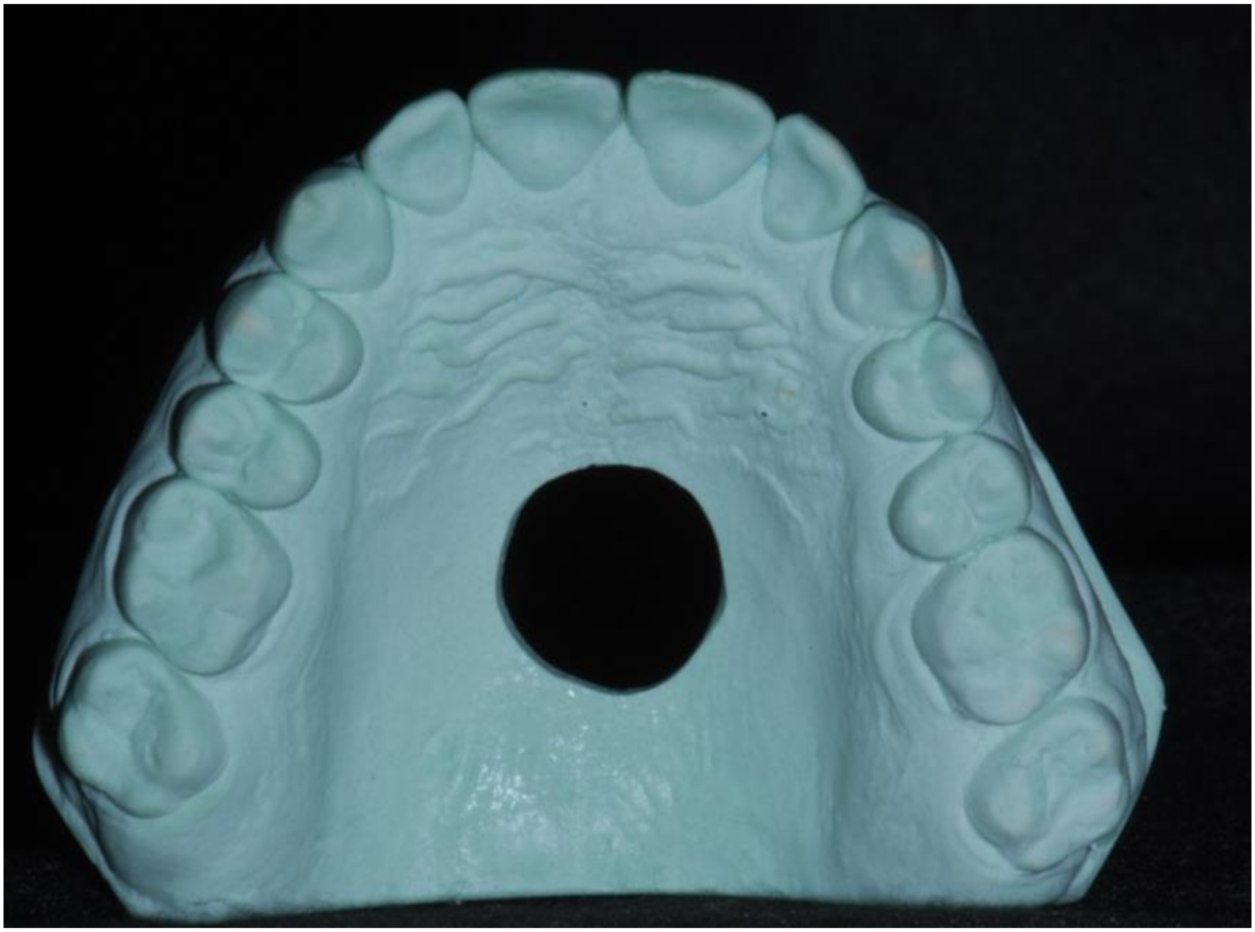

Figura 4. Abertura na região do palato concluída com objetivo de aumentar a eficiência da ação do vácuo durante a confecção do protetor.

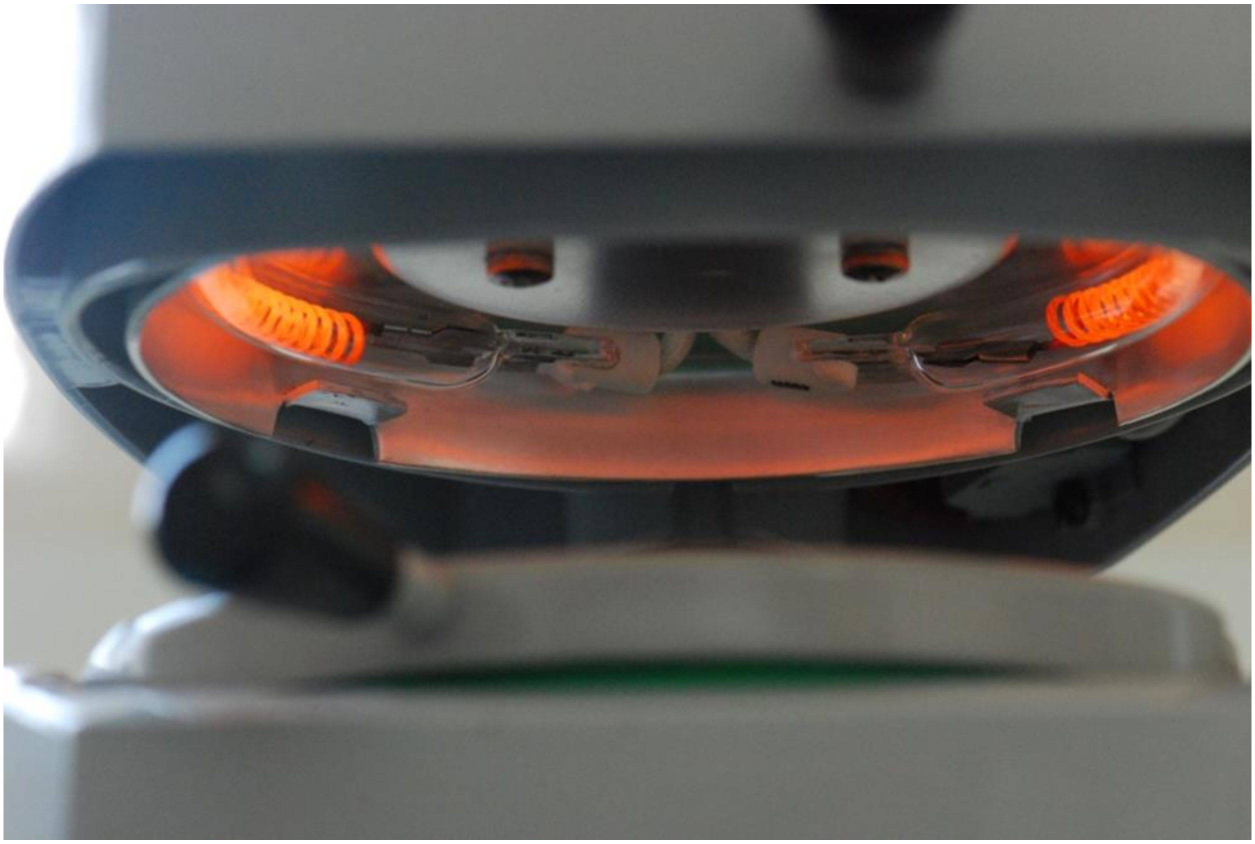

Figura 5. Processo de aquecimento da placa de EVA em plastificadora à vácuo.

Figura 6. Placa de EVA (Cor verde) após prensagem à vacuo em plastificadora. Note que o orifício central otimiza o processo de moldagem para obtenção de melhores resultados.

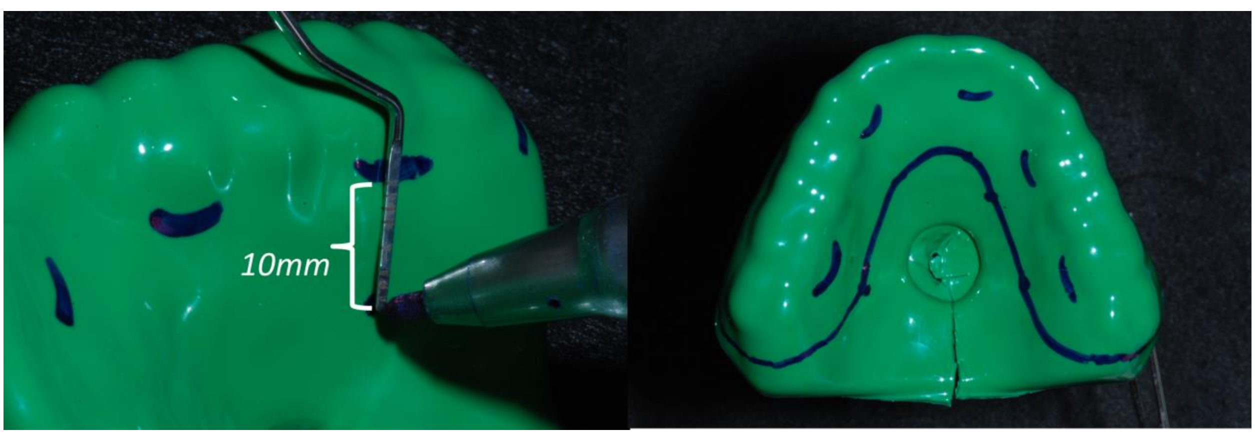

Figura 7. Delimitação da área de corte do protetor bucal demonstrando a região palatina (10mm da margem gengival).

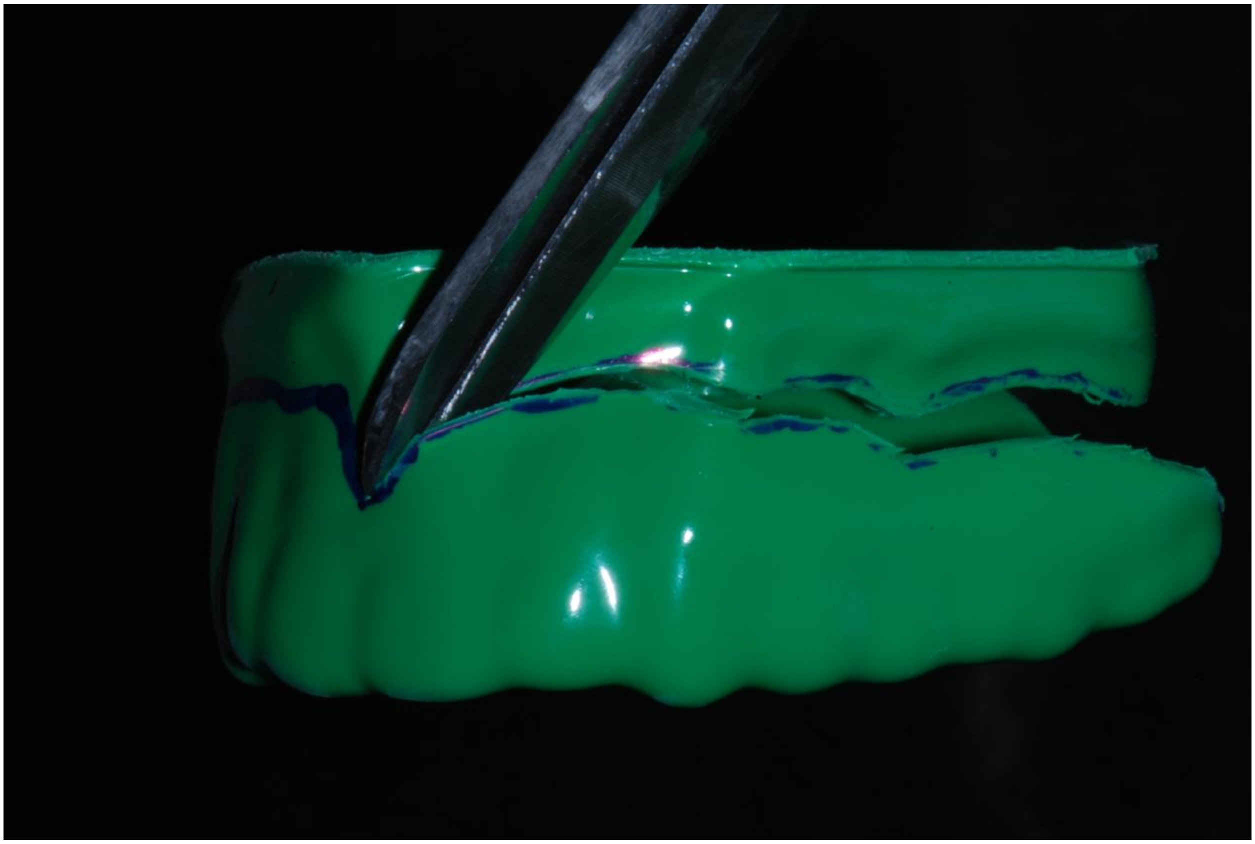

Figura 8. Recorte da placa de EVA na região vestibular seguindo as marcações realizadas na região de fundo de vestíbulo.

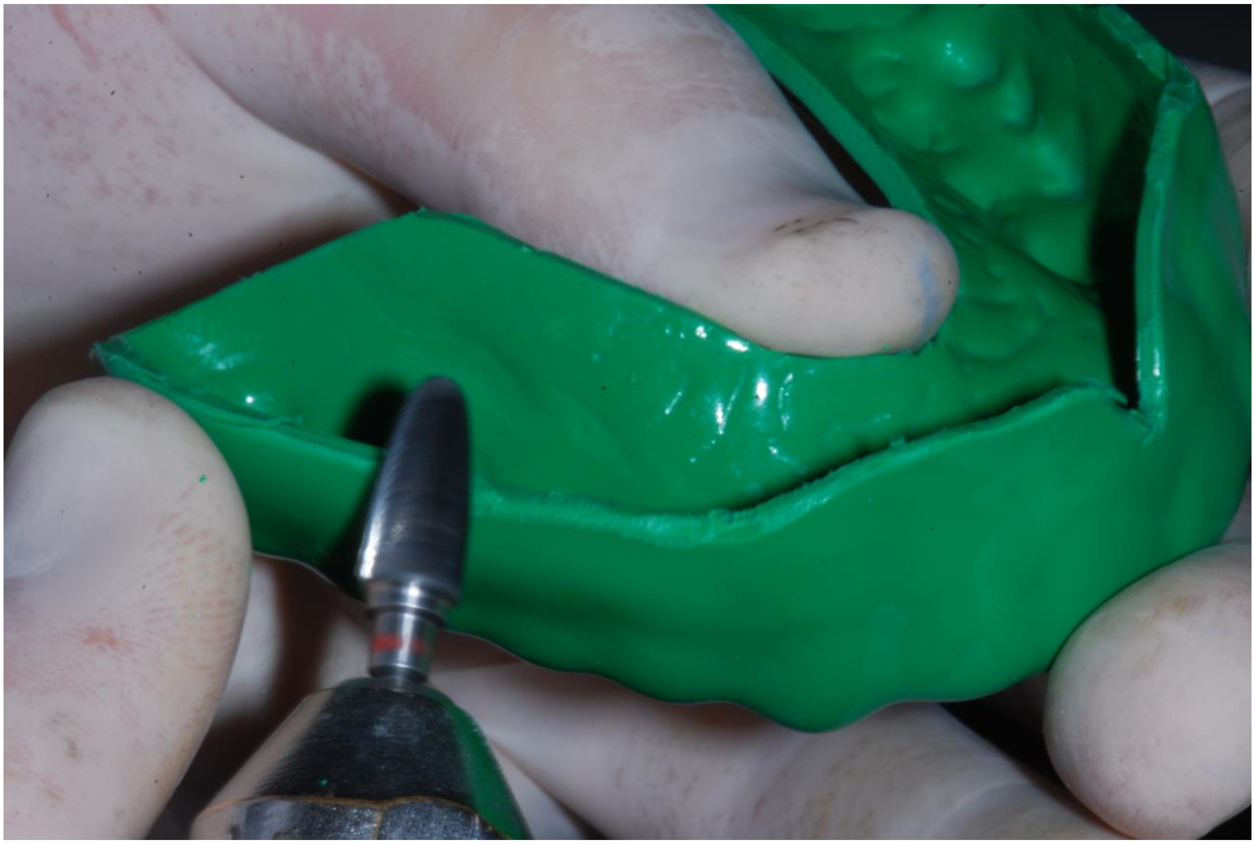

Figura 9. Acabamento da área de recorte com broca maxicut.

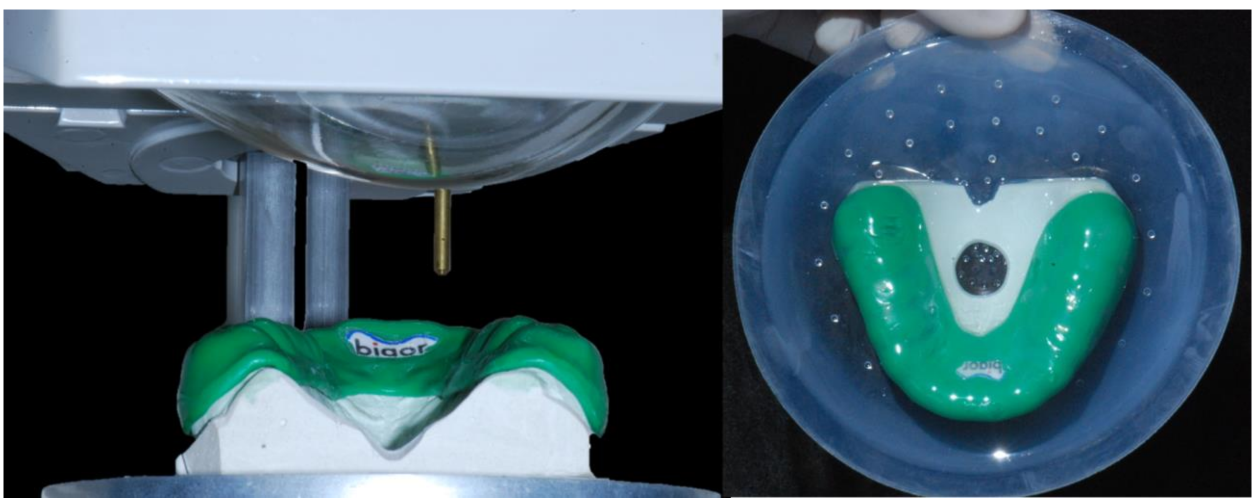

Figura 10. Plastificação e processo de moldagem da segunda placa de EVA (Cor transparente). Note a forma ovalada da placa de EVA durante o processo de aquecimento.

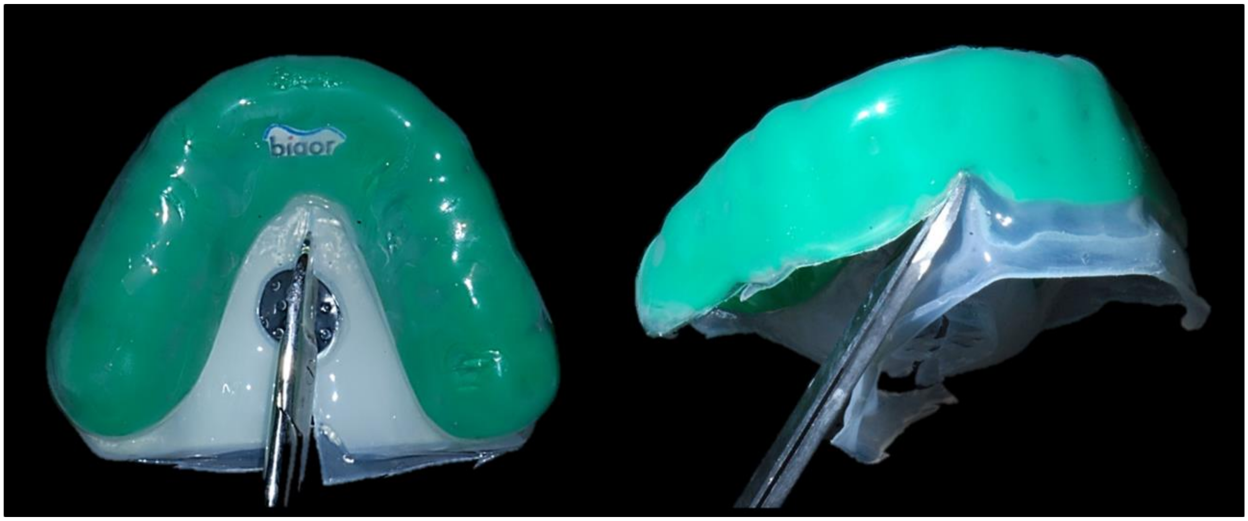

Figura 11. Recorte da segunda placa de EVA. Note que a delimitação da área de recorte feita inicialmente é mantida durante esta etapa e a primeira placa é utilizada como guia para o segundo recorte.

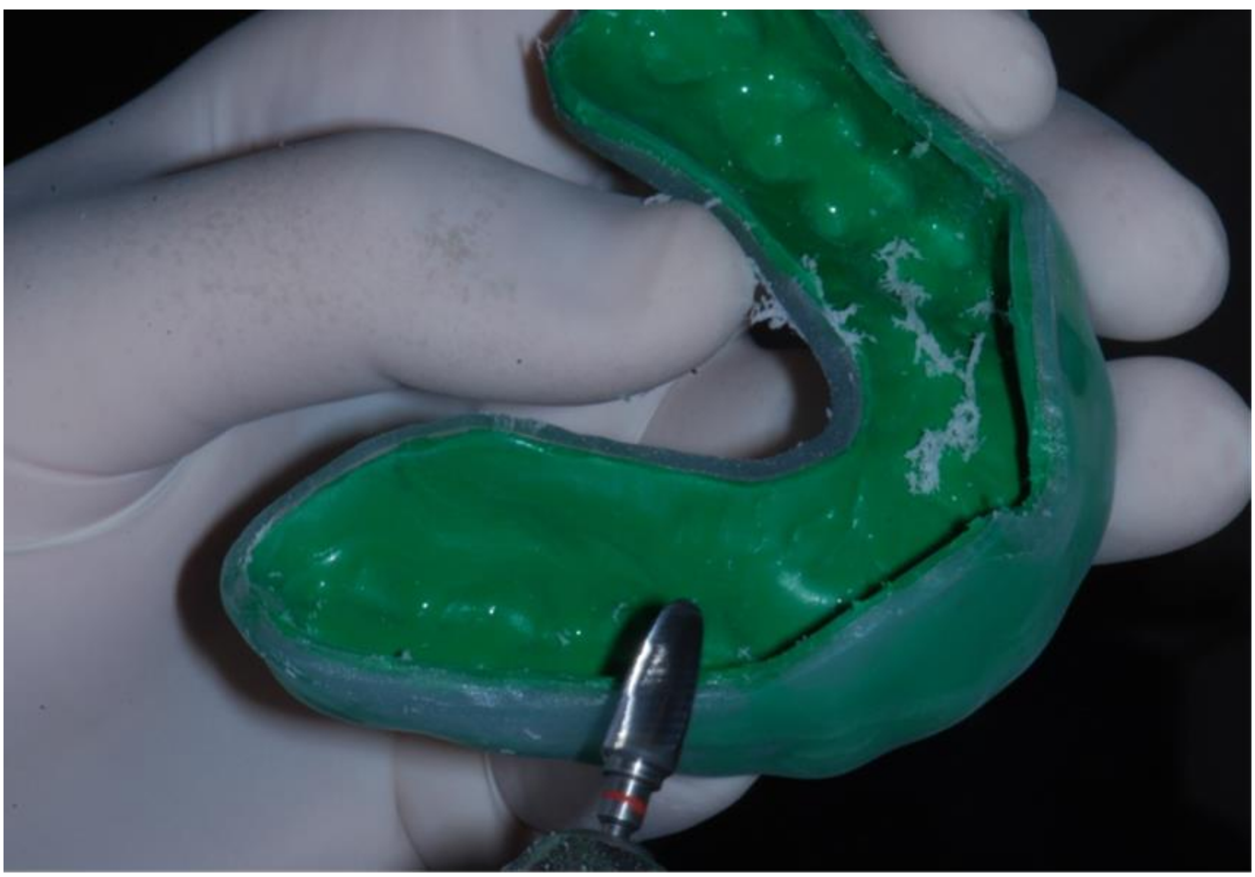

Figura 12. Acabamento da superfície do segundo recorte.

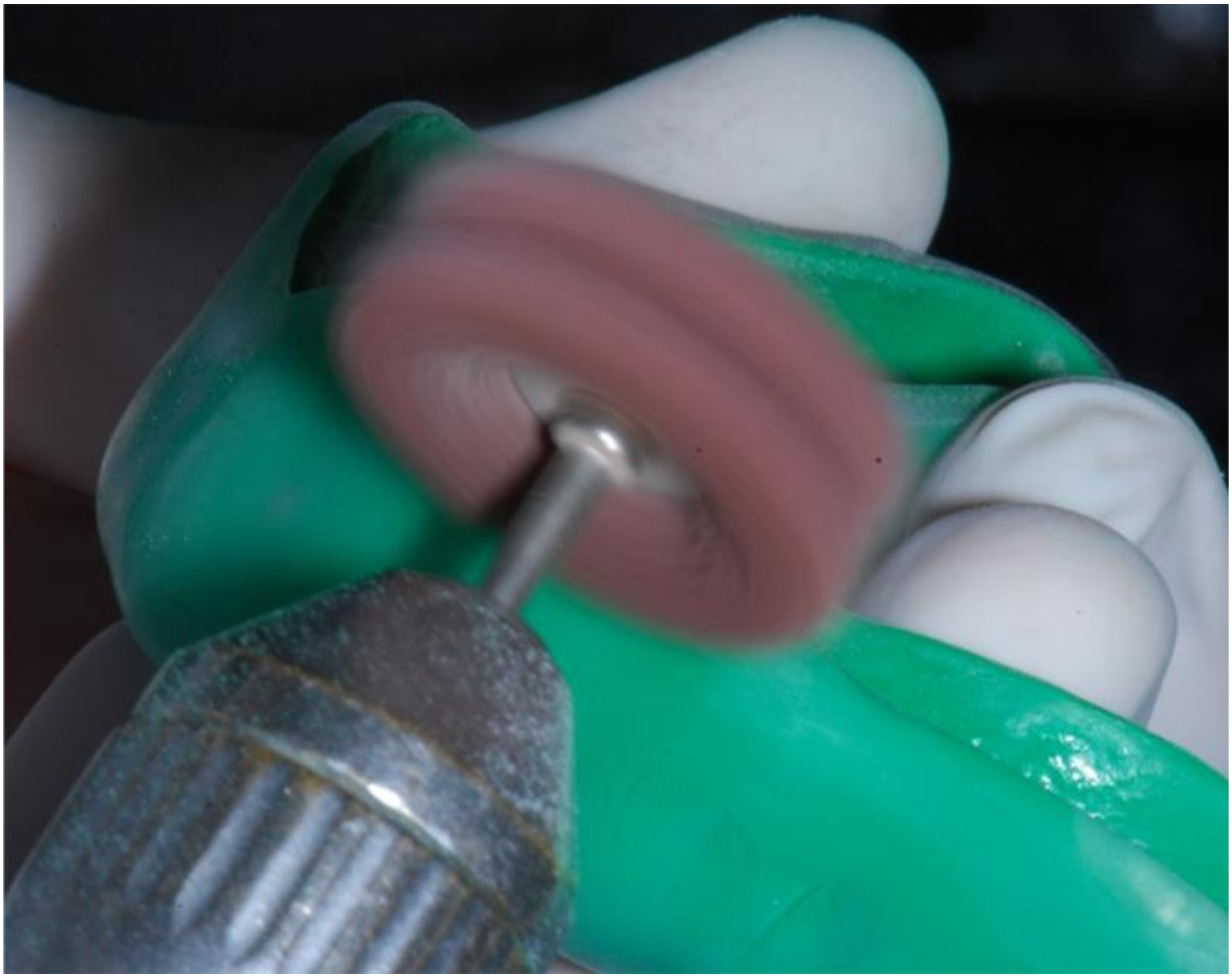

Figura 13. Polimento com ponta Exacerapol em baixa rotação da superfície do protetor bucal.

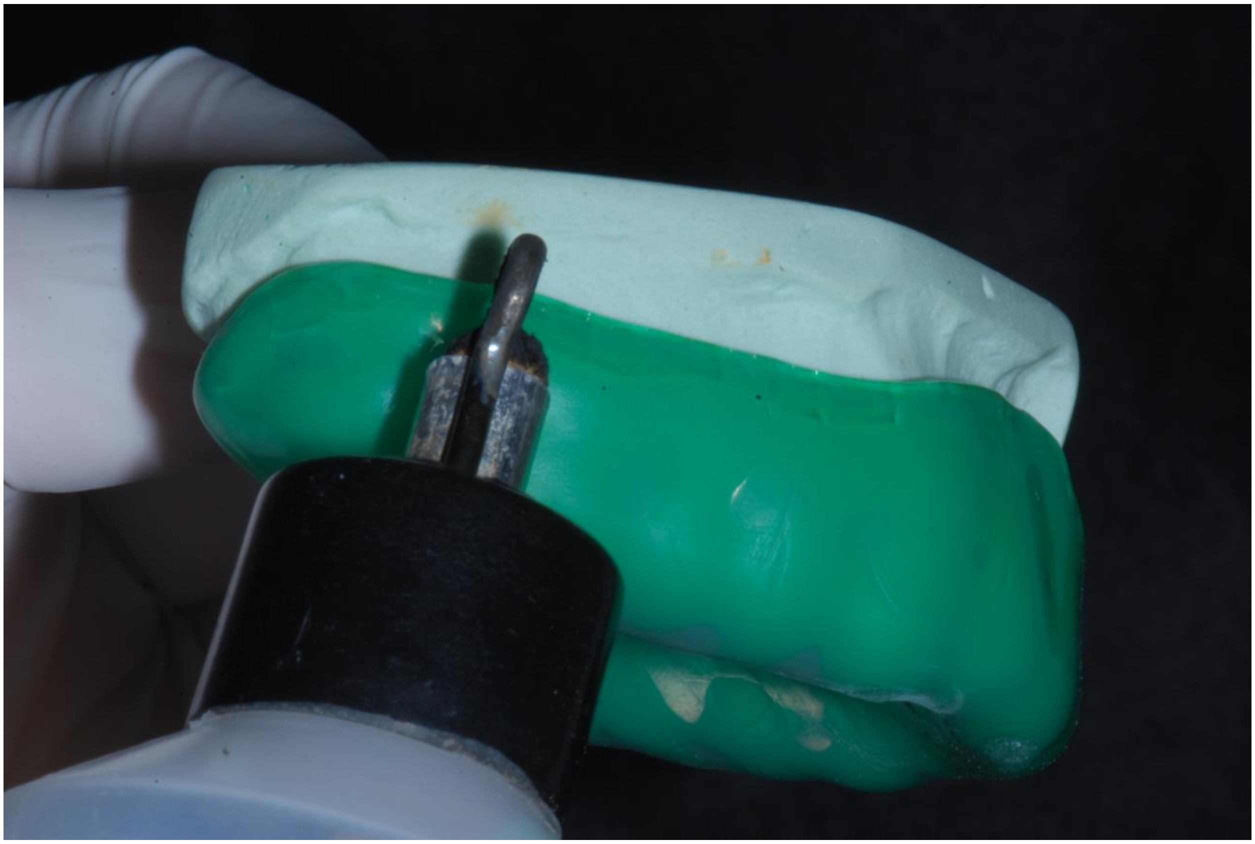

Figura 14. Termoplastificação moderada com lamparina Hannau da superfície de recorte do protetor bucal com objetivo de melhorar a textura de superfície.

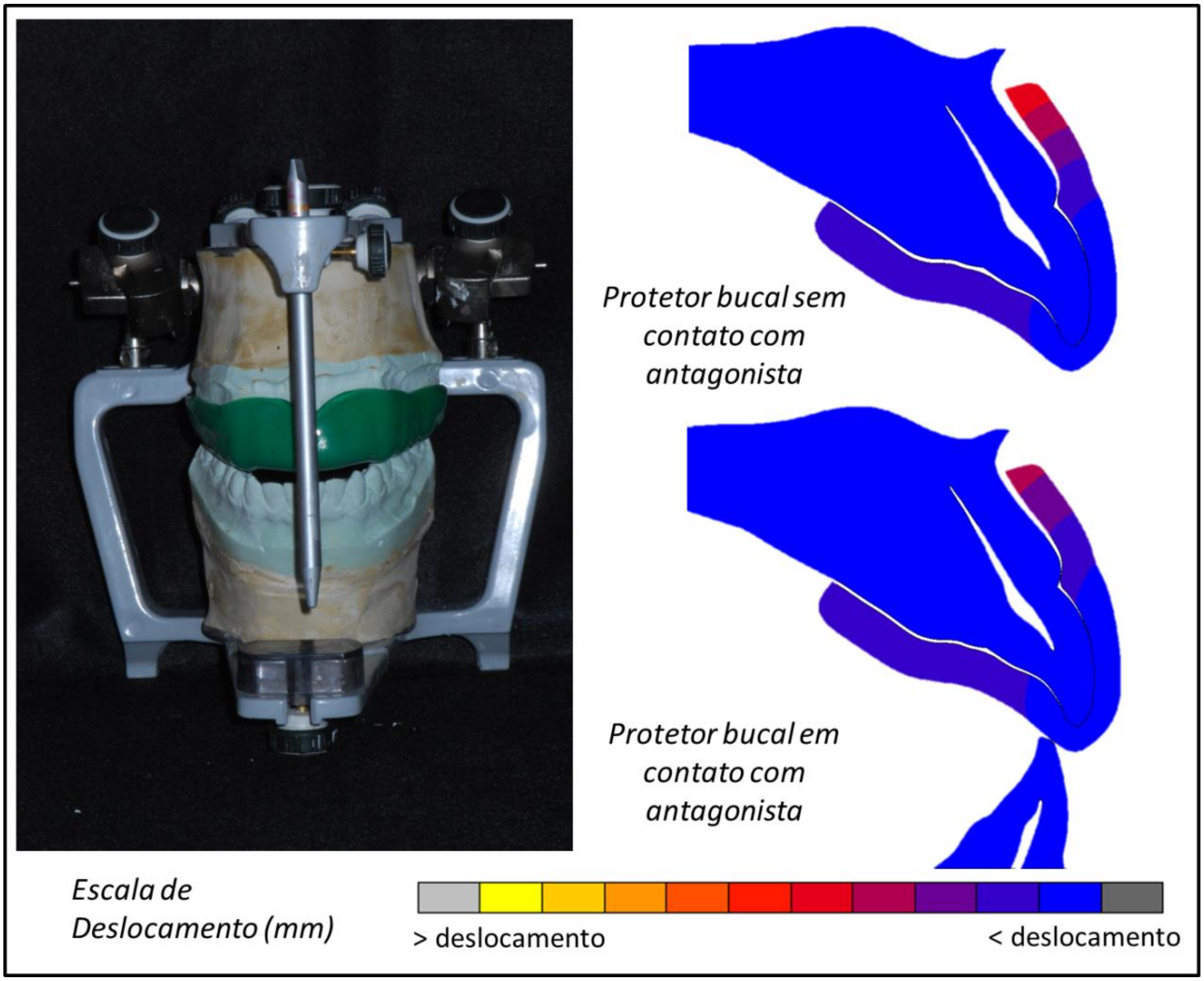

Figura 15. Montagem em articulador para ajuste dos contatos oclusais. Análise por elementos finitos do deslocamento do protetor bucal em função do contato com os dentes antagonistas. Cores amarelas e alaranjadas demonstram maiores deslocamentos. Note que na ausência de contato oclusal existe maior deslocamento do protetor bucal.

Figura 16. Protetor bucal personalizado finalizado (Face vestibular, palatina e oclusal demonstrando a obtenção de detalhes anatômicos do paciente).

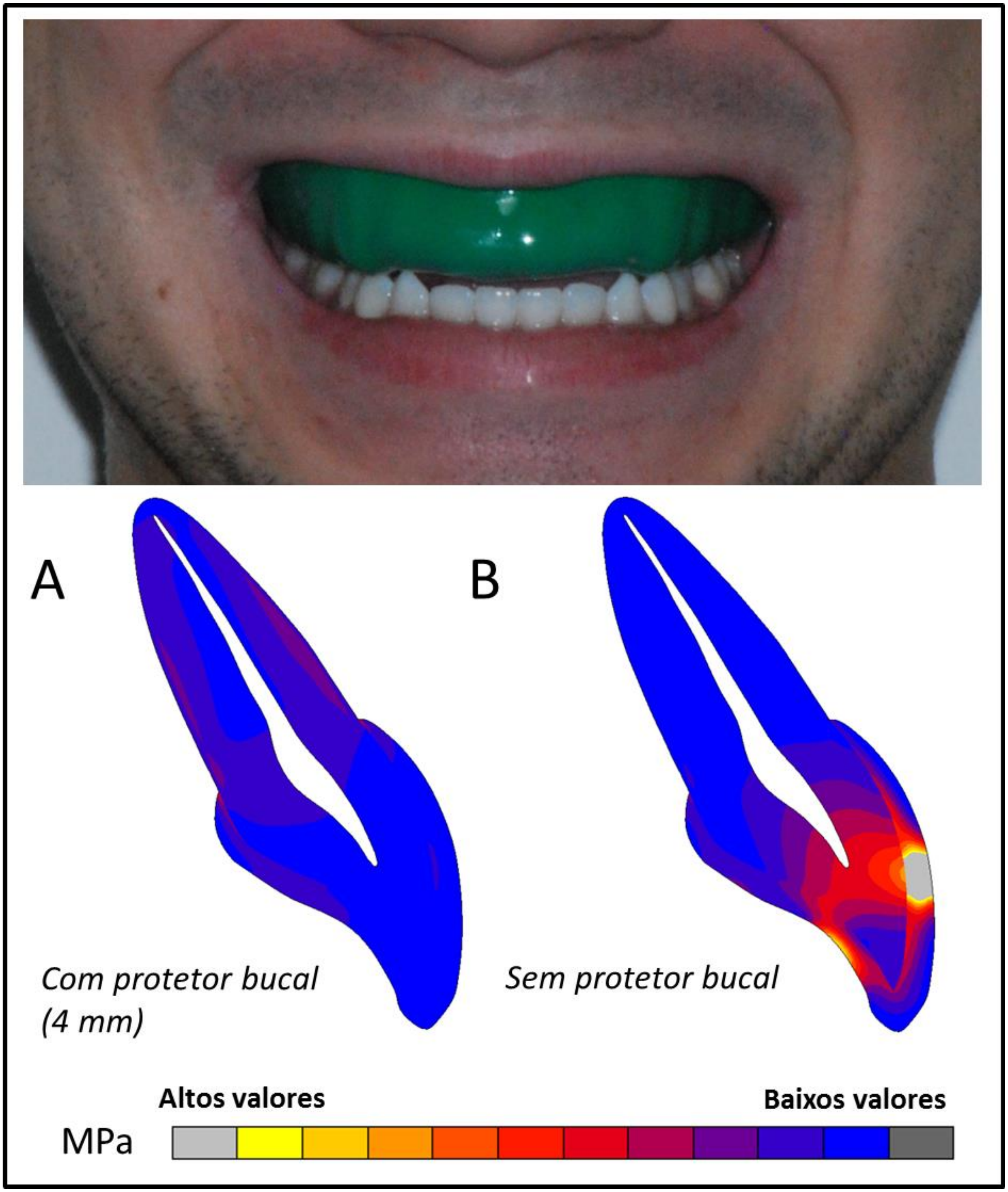

Figura 17. Análise de tensões (von Mises) pelo método de elementos finitos da utilização de protetores bucais. Cores amarelas e vemelhas indicam altos níveis de

concetração de tensões enquanto cores azuis e roxas indicam baixos níveis de concentração de tensões.

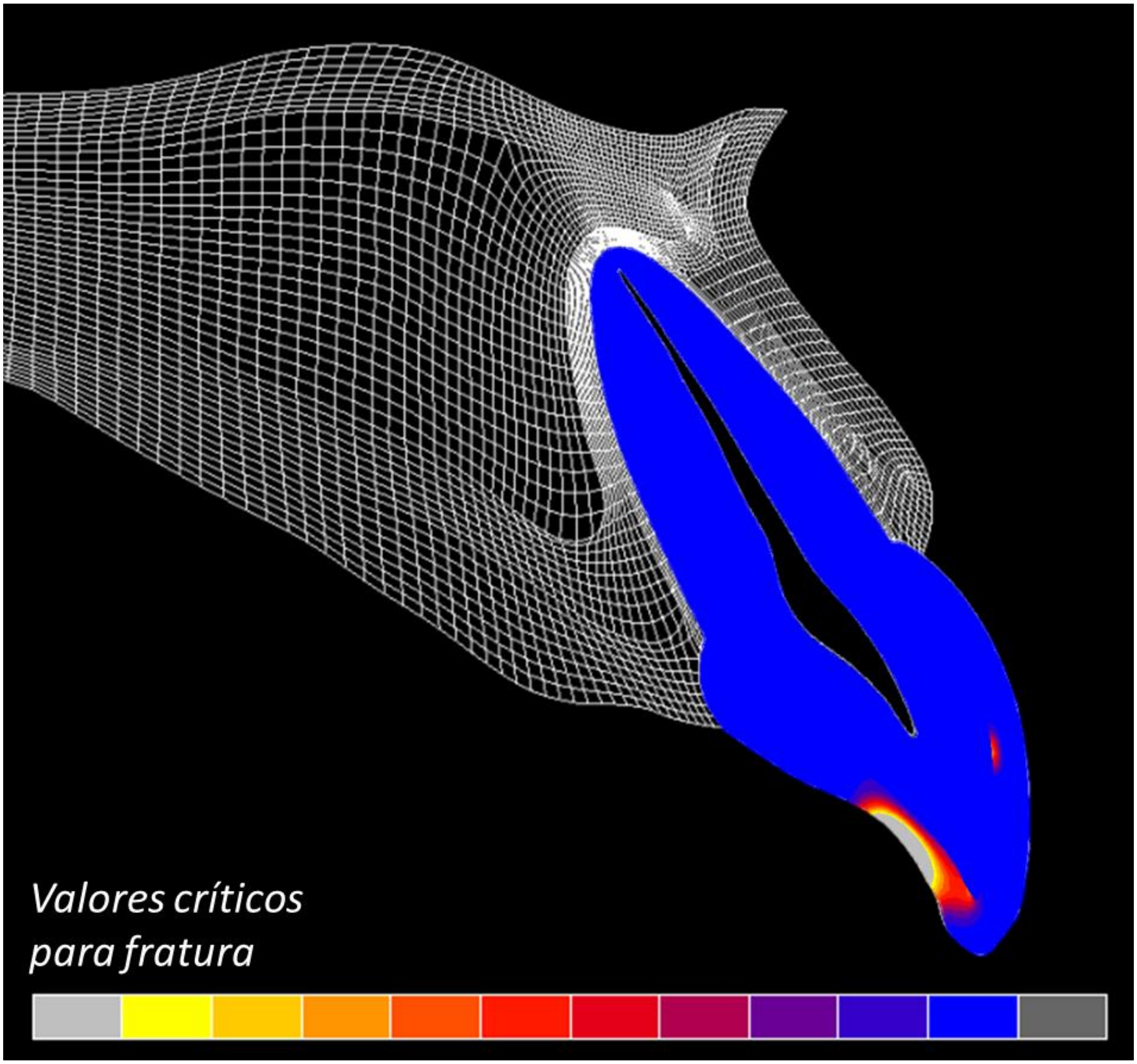

Figura 18. Análise computacional demonstrando áreas de com alta possibilidades de fratura frente a impacto sem utilização de protetores bucais. Cores amarelas e alaranjados demonstram locais críticos para fratura.

CONSIDERAÇÕES FINAIS

4- CONSIDERAÇÕES FINAIS

A prática de esportes de contato está altamente relacionado com a ocorrência de traumas dento-alveolares (Newsome et al., 2001; Low, 2002; Farrington et al., 2012). Diversos tipos de traumas dentários podem ocorrer em função da energia gerada pelo impacto. Dentre os tipos de traumatismos dento-alveoares, os mais comuns são representados pelas fraturas de esmalte e dentina coronária (Lauridsen et al., 2012). No entanto, as injúrias dento-alveolares podem apresentar prognóstico desfavorável principalmente nos casos de avulsões dentárias (Andersson et al., 2012). A fim de reduzir os efeitos deletérios do traumatismo dento-alveolar, os protetores bucais foram desenvolvidos e atualmente são amplamente utilizados por praticantes de esportes de contato.

Embora existam diversos relatos a respeito da capacidade de absorção de impacto de protetores bucais os mecanismos de absorção de impacto permanecem obscuros. Isso se deve principalmente a variabilidade de modelos experimentais desenvolvidos. Dentre os modelos experimentais utilizados, a grande maioria dos estudos utilizam modelos de resina acrílica (Typodont) para aplicação de impactos. Entretanto, modelos de resina acrílica são unidades mono-estruturais (material com propriedades isotrópicas/lineares) não capazes de reproduzir esmalte, dentina e ligamento periodontal; por isso, não simulam o comportamento biológico de tensão e deformação frente a aplicação de um carregamento (impacto). Além disso, o ligamento periodontal tem influência significativa na capacidade de absorção de impacto e estudos tentaram criar o ligamento periodontal por meio de simulação com materiais elásticos (Soares et al., 2011). Neste sentido, a utilização de modelo experimental dento-alveolar obtido de mandíbulas bovinas combina a presença do ligamento periodontal com estruturas anisotrópicas e orgânicas como esmalte, dentina e osso alveolar. Os resultados desse estudo demostraram que as respostas do protetor bucal personalizado relatadas na literatura parecem ser subestimadas devido a capacidade de absorção de impacto ter alcançado níveis de 98%. Ademais, o ensaio experimental foi validado pela análise não-linear de impacto comprovando que o modelo experimental bovino é eficaz para a análise biomecânica de protetores bucais.

A performance mecânica de protetores bucais pode ser influenciada por diversos fatores dentre eles: tipo de material utilizado para confecção, adaptação, extensão das margens do protetor, conforto durante uso e espessura. No entanto, a espessura do protetor bucal é um dos fatores críticos para a avaliação das respostas frente ao impacto. Estudos prévios definiram que existe relação inversa entre a espessura do protetor bucais e a capacidade de absorção de impactos. Ou seja, quanto maior a espessura do protetor bucal, menor é a força transmitida às estruturas dento-alveolares. A análise não-linear de impacto realizada por meio do método de elementos finitos demonstrou que os protetores bucais estão relacionados com a diminuição das tensões e deformações independentemente da espessura do protetor bucal. A análise também demonstrou relação direta entre a espessura do protetor bucal e o padrão de deslocamento do protetor bucal frente ao impacto. Na medida em que aumenta-se a espessura verificou-se diminuição dos deslocamentos na face vestibular do protetor. Este menor deslocamento pode representar maior estabilidade e consequentemente maior efetividade. Entretanto, protetores bucais confeccionados com 5 ou 6 mm estão relacionados com problemas de aceitação e conforto durante o uso. Ademais, protetores espessos dificultam o fechamento dos lábios acarretando possíveis lesões de tecidos moles. E ainda pode afetar negativamente na performance de atletas de alto rendimento por interferir na capacidade respiratória, influenciando a performance aeróbica. Nesse sentido, com base nos resultados apresentados, protetores bucais devem apresentar espessura média de 4 mm, associando efetividade biomecânica, conforto e eficiência.

Diversas modificações no desing e na composição dos protetores bucais tem sido propostas com objetivo de aumentar a eficiência e capacidade de absorção de impactos. Inclusão de células de ar, confecção em camadas, inserção de materiais rígidos estão entre algumas das propostas desenvolvidas. Os resultados do presente estudo demonstram que a inserção de material rígido na camada interna do protetor bucal reduz os níveis de deslocamento mantendo os mesmos níveis de tensão e deformação de um protetor bucal personalizado. Além da modificação no desing dos protetores bucais, o ajuste do protetor bucal personalizado registrando os contatos oclusais com os dentes antagonistas também minimiza a probabilidade de deslocamento do protetor bucal, contribuindo para sua correta função.

A análise não-linear de impacto por elementos finitos mostrou-se eficaz para a avaliação do comportamento biomecânico de protetores bucais. De maneira geral, a análise demostrou que o protetor bucal de EVA é capaz de diminuir os níveis de tensão e deformações geradas pelo impacto. O protetor bucal é responsável por aumentar a superfície de contato com o objeto de impacto. Além disso, o comportamento elástico e a histérese do EVA são promovem absorção significativa das tensões geradas pelo impacto. Por meio deste mecanismo, o protetor bucal aumenta o tempo necessário para atingir o pico de transmissão de forças do impacto, o que acarreta na distribuição das tensões para a estrutura dentinária radicular e tecidos de suporte. Na ausência do protetor bucal, as tensões geradas pelo impacto horizontal são concentradas em alta intensidade na estrutura coronária em curto espaço de tempo. Por outro lado, utilizando o critério de von Mises modificado crítico, verificou-se que a área de maior possibilidade para ocorrência de falha estrutural ou fratura localiza-se na face palatina. Nessa situação, a coroa dentária sofre flexão, com área sujeita a altas tensões de compressão na face vestibular e tensões de tração na superfície palatina o que contribui para fraturas coronárias.

O uso de metodologias não destrutivas associadas a métodos computacionais como o método de elementos finitos colaboram de forma substancial para a avaliação biomecânica de protetores bucais. Contudo, os ensaios in vitro possuem limitações inerentes e que requerem validação por diferentes metodologias. Apesar das limitações de um estudo in-vitro e computacional, os resultados do presente estudo demonstraram que protetores bucais personalizados de EVA são altamente eficazes na absorção de impactos e devem ser utilizados durante a prática de esportes para prevenção de traumatismos dento-alveolares. Como propostas futuras geradas a partir destes nossos estudos cabe primordialmente o delineamento de estudos clínicos de avaliação de protetores bucais nestas condições testadas e buscar ainda o desenvolvimento de placas de EVA com a inserção de camadas intermediárias rígidas buscando desenvolver novos produtos. Devido ao processo contínuo e progressivo de geração e transmissão do conhecimento com evidência científica este trabalho destaca ainda que o cirurgiões dentistas devem estar atentos as inovações na prevenção de traumatismos dento-alveolares sendo o uso de protetores bucais personalizados uma estratégia a ser popularizada nos consultórios particulares e serviços públicos e assim reduzir intervenções reabilitadoras complexas quando do trauma em dentes anteriores em crianças e atletas.

CONCLUSÕES

5- CONCLUSÕES

Dentro das limitações deste estudo que envolveu 4 estudos laboratoriais e computacionais, além de relato de caso clínico pode-se concluir que:

- Protetores bucais personalizados são capazes de diminuir os níveis de tensão e deformação no complexo dento-alveolar durante impactos alterando o ponto de concentração de tensões para à dentina radicular em níveis abaixo da resistência máxima à compressão e tração da dentina.
- Na ausência de protetores bucais o impacto horizontal cria condição crítica para fratura dentária na região palatina da coroa dentária. A presença de protetor, diminui de forma significativa esta condição crítica.
- Em testes de impacto com dispositivo pendular e modelo experimental dento-alveolar bovino concluiu-se que a velocidade do impacto determinada pelas diferentes angulações (90, 60 ou 45º), objeto de impacto (bola de baseball ou de metal) e a presença de protetor bucal influenciam significativamente as tensões e deformações geradas frente a um impacto.
- A velocidade determinada pela angulação de 90º promoveu os maiores valores de tensão e deformação independentemente do tipo de objeto de impacto (bola de baseball ou metal)
- Protetores bucais personalizados apresentaram capacidade de absorção de 98% da energia gerada em impacto com base nas mensurações com extensometria e 95% pela análise de elementos finitos.

- Os resultados do ensaio experimental de extensometria e os encontrados nos modelos de elementos finitos foram mutuamente validados pelo similaridade de comportamento, portanto ambas metodologias são consideradas eficientes e devem ser vistas como complementares para avaliação do comportamento biomecânico de protetores bucais. Dessa forma, o uso do dispositivo pêndular desenvolvido neste estudo também mostrou-se eficiente.
- Protetores bucais personalizados devem ser confeccionados na espessura de aproximadamente 4mm.
- A inserção de material rígido no interior do protetor bucal (camada média) diminui os níveis de deslocamento do protetor bucal frente ao impacto sem modificar a eficiência na redução das tensões e deformações.
- O ajuste do protetor bucal adaptando-o à oclusão do paciente é imprecindível para obtenção do maior número de contatos oclusais e consequentemente reduzir o deslocamento do protetor bucal durante o impacto.

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6- REFERÊNCIAS

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ANEXOS

7- Cartas de aceite e Normas dos Periódicos

7.2.1 Cartas de aceite

-------- Mensagem original --------
Assunto: AJD Paper accepted
Data: 2014-11-25 12:07
De: Franklin Garcia-Godoy <godoy@amjdent.com>
Para: Carlos Soares <carlosjsoares@umuarama.ufu.br>
Cópia: aversIui@uthsc.edu

RE: MODIFYING THE BIOMECHANICAL RESPONSE OF MOUTHGUARDS WITH HARD INSERTS: A FINITE ELEMENT STUDY.

Dr. Soares:

I am pleased to inform you that your revised manuscript has been accepted for publication in the AMERICAN JOURNAL OF DENTISTRY.

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Again, thank you for considering the AMERICAN JOURNAL OF DENTISTRY for publication of your work.

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7.2.2 Normas dos Periódicos

Capítulo 1 e 4 – Dental Traumatology

Dental Traumatology

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Online ISSN: 1600-9657

Author Guidelines

Content of Author Guidelines: 1. General, 2. Ethical Guidelines, 3. Submission of Manuscripts, 4. Manuscript Types Accepted, 5. Manuscript Format and Structure, 6. After Acceptance

Useful Websites: Submission Site, Articles published in Dental Traumatology, Author Services,Wiley-Blackwell's Ethical Guidelines, Guidelines for Figures

1. GENERAL

Dental Traumatology is an international journal which aims to convey scientific and clinical progress in all areas related to adult and pediatric dental traumatology. It aims to promote communication among clinicians, educators, researchers, administrators and others interested in dental traumatology. The journal publishes original scientific articles, review articles in the form of comprehensive reviews or mini reviews of a smaller area, short communication about clinical methods and techniques and case reports. The journal focuses on the following areas related to dental trauma:

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It is a requirement that all authors have been accredited as appropriate upon submission of the manuscript. Contributors who do not qualify as authors should be mentioned under Acknowledgements.

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• Log-in and select 'Author Centre.'

3.2. Submitting Your Manuscript

• After you have logged into your 'Author Centre', submit your manuscript by clicking the submission link under 'Author Resources'.

• Enter data and answer questions as appropriate. You may copy and paste directly from your manuscript and you may upload your pre-prepared covering letter.

• Click the 'Next' button on each screen to save your work and advance to the next screen.

• You are required to upload your files.

- Click on the 'Browse' button and locate the file on your computer.
- Select the designation of each file in the drop down next to the Browse button.
- When you have selected all files you wish to upload, click the 'Upload Files' button.

• To allow double blinded review, please submit (upload) your main manuscript and title page as separate files. Please upload:

- Your manuscript without title page under the file designation 'main document'
- Figure files under the file designation 'figures'.
- The title page, Acknowledgements and Conflict of Interest Statement where applicable, should be uploaded under the file designation 'title page'

• Review your submission (in HTML and PDF format) before completing your submission by sending it to the Journal. Click the 'Submit' button when you are finished reviewing. All documents uploaded under the file designation 'title page' will not be viewable in the html and pdf format you are asked to review in the end of the submission process. The files viewable in the html and pdf format are the files available to the reviewer in the review process.

3.3. Manuscript Files Accepted

Manuscripts should be uploaded as Word (.doc) or Rich Text Format (.rft) files (not write-protected) plus separate figure files. GIF, JPEG, PICT or Bitmap files are acceptable for submission, but only high-resolution TIF or EPS files are suitable for printing. The files uploaded as main manuscript documents will be automatically converted to HTML and PDF on upload and will be used for the review process. The files uploaded as title page will be blinded from review and not converted into HTML and PDF. The main manuscript document file must contain the entire manuscript including abstract, text, references, tables, and figure legends, but *no* embedded figures. In the text, please reference figures as for instance 'Figure 1', 'Figure 2' etc to match the tag name you choose for the individual figure files uploaded. Manuscripts should be formatted as described in the Author Guidelines below.

3.4. Blinded Review

All manuscripts submitted to *Dental Traumatology* will be reviewed by two experts in the field.*Dental Traumatology* uses double blinded review. The names of the reviewers will thus not be disclosed to the author submitting a paper and the name(s) of the author(s) will not be disclosed to the reviewers.

To allow double blinded review, please submit (upload) your main manuscript and title page as separate files.

Please upload:

• Your manuscript without title page under the file designation 'main document'

• Figure files under the file designation 'figures'

• The title page, Acknowledgements and Conflict of Interest Statement where applicable, should be uploaded under the file designation 'title page'

All documents uploaded under the file designation 'title page' will not be viewable in the html and pdf format you are asked to review in the end of the submission process. The files viewable in the html and pdf format are the files available to the reviewer in the review process.

3.5. Suggest a Reviewer

Dental Traumatology attempts to keep the review process as short as possible to enable rapid publication of new scientific data. In order to facilitate this process, please suggest the names and current email addresses of a potential international reviewer whom you consider capable of reviewing your manuscript. In addition to your choice the journal editor will choose one or two reviewers as well. When the review is done you will be notified under 'Manuscripts with decision' and through e-mail.

3.6. Suspension of Submission Mid-way in the Submission Process

You may suspend a submission at any phase before clicking the 'Submit' button and save it to submit later. The manuscript can then be located under 'Unsubmitted Manuscripts' and you can click on 'Continue Submission' to continue your submission when you choose to.

3.7. E-mail Confirmation of Submission

After submission you will receive an e-mail to confirm receipt of your manuscript. If you do not receive the confirmation e-mail after 24 hours, please check your e-mail address carefully in the system. If the e-mail address is correct please contact your IT department. The error may be caused by some sort of spam filtering on your e-mail server. Also, the e-mails should be received if the IT department adds our e-mail server (uranus.scholarone.com) to their whitelist.

3.8. Manuscript Status

You can access ScholarOne Manuscripts (formerly known as Manuscript Central) any time to check your 'Author Center' for the status of your manuscript. The Journal will inform you by e-mail once a decision has been made.

3.9. Submission of Revised Manuscripts

To submit a revised manuscript, locate your manuscript under 'Manuscripts with Decisions' and click on 'Submit a Revision'. Please remember to delete any old files uploaded when you upload your revised manuscript. Please also remember to upload your manuscript document separate from your title page.

4. MANUSCRIPT TYPES ACCEPTED

Original Research Articles in all areas related to adult and pediatric dental traumatology are of interest to *Dental Traumatology*. Examples of such areas are Epidemiology and Social Aspects, Tissue, Periodontal, and Endodontic Considerations, Pediatrics and Orthodontics, Oral and Maxillofacial Surgery/ Transplants / Implants, Esthetics / Restorations / Prosthetics and Prevention and Sports Dentistry.

Review Papers: *Dental Traumatology* commissions review papers of comprehensive areas and mini reviews of small areas. The journal also welcomes uninvited reviews. Reviews should be submitted via the online submission site and are subject to peer-review.

Comprehensive Reviews should be a complete coverage of a subject discussed with the Editor in Chief prior to preparation and submission. Comprehensive review articles should include a description of search strategy of relevant literature, inclusion criteria, evaluation of papers and level of evidence.

Mini Reviews are covering a smaller area and may be written in a more free format.

Case Reports: *Dental Traumatology* accepts Case Reports but these will only be published online and will not be included in the printed version unless specifically requested by the Editor-in-Chief.
Case Reports illustrating unusual and clinically relevant observations are acceptable, but their merit needs to provide high priority for publication in the journal. They should be kept within 3-4 printed pages and need not follow the usual division into material and methods etc, but should have an abstract. The introduction should be kept short. Thereafter the case is described followed by a discussion.

Short Communications of 1-2 pages are accepted for quick publication. These papers need not follow the usual division into Material and Methods, etc., but should have an abstract. They should contain important new information to warrant publication and may reflect improvements in clinical practice such as introduction of new technology or practical approaches. They should conform to a high scientific and a high clinical practice standard.

Letters to the Editor, if of broad interest, are encouraged. They may deal with material in papers published in Dental Traumatology or they may raise new issues, but should have important implications.

Meetings: advance information about and reports from international meetings are welcome, but should not be submitted via the online submission site, but send directly to the journal administrator Karin Andersson at dtoffice@qualitynet.net

5. MANUSCRIPT FORMAT AND STRUCTURE

5.1. Format

Language: The language of publication is English. Authors for whom English is a second language must have their manuscript professionally edited by an English speaking person before submission to make sure the English is of high quality. It is preferred that manuscript is professionally edited. A list of independent suppliers of editing services can be found athttp://authorservices.wiley.com/bauthor/english_language.asp. All services are paid for and arranged by the author, and use of one of these services does not guarantee acceptance or preference for publication.

Abbreviations, Symbols and Nomenclature: Abbreviations should be kept to a minimum, particularly those that are not standard. Non-standard abbreviations must be used three or more times and written out completely in the text when first used. Consult the following sources for additional abbreviations: 1) CBE Style Manual Committee. Scientific style and format: the CBE manual for authors, editors, and publishers. 6th ed. Cambridge: Cambridge University Press; 1994; and 2) O'Connor M, Woodford FP. Writing scientific papers in English: an ELSE-Ciba Foundation guide for authors. Amsterdam: Elsevier-Excerpta Medica; 1975.

Font: When preparing your file, please use only standard fonts such as Times, Times New Roman or Arial for text, and Symbol font for Greek letters, to avoid inadvertent character substitutions. In particular, please do not use Japanese or other Asian fonts. Do not use automated or manual hyphenation. Use double spacing when writing.

5.2. Structure

All papers submitted to *Dental Traumatology* should include: Title Page, Abstract, Main text, References and Tables, Figures, Figure Legends, Conflict of Interest Statement and Acknowledgements where appropriate. Title page, Conflict of Interest Statement and any Acknowledgements must be submitted as separate files and uploaded under the file designation Title Page to allow blinded review. Manuscripts must conform to the journal style. Manuscripts not complying with the journal style will be returned to the author(s).

Title Page: should be uploaded as a separate document in the submission process under the file designation 'Title Page' to allow blinded review. It should include: Full title of the manuscript, author(s)' full names (Family names should be underlined) and institutional affiliations including city, country, and the name and address of the corresponding author. If the author does not want the e-mail address to be published this must be clearly indicated. The title page should also include a running title of no more than 60 characters and 3-6 keywords.

Abstract is limited to 250 words in length and should contain no abbreviations. The abstract should be included in the manuscript document uploaded for review as well as inserted separately where specified in the submission process. The abstract should convey the essential purpose and message of the paper in an abbreviated form. For original articles the abstract should be structured with the following headings: Background/Aim, Material and

Methods, Results and Conclusions. For other article types, please choose headings appropriate for the article.

Main Text of Original Articles should be divided into Introduction, Material and Methods, Results and Discussion. During the editorial process reviewers and editors frequently need to refer to specific portions of the manuscript, which is difficult unless the pages are numbered. Authors should number all of the pages consecutively.

Introduction should be focused, outlining the historical or logical origins of the study and not summarize the results; exhaustive literature reviews are inappropriate. Give only strict and pertinent references and do not include data or conclusions from the work being reported. The introduction should close with the explicit statement of the specific aims of the investigation or hypothesis tested.

Materials and Methods must contain sufficient detail such that, in combination with the references cited, all clinical trials and experiments reported can be fully reproduced. As a condition of publication, authors are required to make materials and methods used freely available to academic researchers for their own use. Describe your selection of observational or experimental participants clearly. Identify the method, apparatus and procedures in sufficient detail. Give references to established methods, including statistical methods, describe new or modify methods. Identify precisely all drugs used including generic names and route of administration.

(i) Clinical trials should be reported using the CONSORT guidelines available at www.consort-statement.org. A CONSORT checklist should also be included in the submission material. All manuscripts reporting results from a clinical trial must indicate that the trial was fully registered at a readily accessible website, e.g., www.clinicaltrials.gov.

(ii) Experimental subjects: experimentation involving human subjects will only be published if such research has been conducted in full accordance with ethical principles, including the World Medical Association Declaration (version, 200**8**http://www.wma.net/en/30publications/10policies/b3/index.html) and the additional requirements, if any, of the country where the research has been carried out. Manuscripts must be accompanied by a statement that the experiments were undertaken with the understanding and written consent of each subject and according to the above mentioned principles. A statement regarding the fact that the study has been independently reviewed and approved by an ethical board should also be included. Editors reserve the right to reject papers if there are doubts as to whether appropriate procedures have been used.

(iii) Suppliers of materials should be named and their location (town, state/county, country) included.

Results should present the observations with minimal reference to earlier literature or to possible interpretations. Present your results in logical sequence in the text, tables and illustrations giving the main or most important findings first. Do not duplicate data in graphs and tables.
Discussion may usually start with a brief summary of the major findings, but repetition of parts of the Introduction or of the Results sections should be avoided. The section should end with a brief conclusion and a comment on the potential clinical relevance of the findings. Link the conclusions to the aim of the study. Statements and interpretation of the data should be appropriately supported by original references.

Main Text of Review Articles comprises an introduction and a running text structured in a suitable way according to the subject treated. A final section with conclusions may be added.

Acknowledgements: Under acknowledgements please specify contributors to the article other than the authors accredited. Acknowledgements should be brief and should not include thanks to anonymous referees and editors.

Conflict of Interest Statement: All sources of institutional, private and corporate financial support for the work within the manuscript must be fully acknowledged, and any potential grant holders should be listed. The Conflict of Interest Statement should be included as a separate document uploaded under the file designation 'Title Page' to allow blinded review.

5.3. References

As the Journal follows the Vancouver system for biomedical manuscripts, the author is referred to the publication of the International Committee of Medical Journal Editors: Uniform requirements for manuscripts submitted to biomedical journals. Ann Int Med 1997;126:36-47.

Number references consecutively in the order in which they are first mentioned in the text. Identify references in texts, tables, and legends by Arabic numerals (in parentheses). Use the style of the examples below, which are based on the format used by the US National Library of Medicine in Index Medicus. For abbreviations of journals, consult the 'List of the Journals Indexed' printed annually in the January issue of Index Medicus.
We recommend the use of a tool such as EndNote or Reference Manager for reference management and formatting. EndNote reference styles can be searched for here:www.endnote.com/support/enstyles.asp. Reference Manager reference styles can be searched for here: www.refman.com/support/rmstyles.asp

AJSM Manuscript Submission Guidelines

The *American Journal of Sports Medicine* (AJSM) is the official publication of the American Orthopaedic Society for Sports Medicine.
The editor of AJSM, Bruce Reider, can be contacted via e-mail at breider@ajsm.org.

Manuscripts must not be under simultaneous consideration by any other publication, before or during the peer-review process. Papers presented at AOSSM meetings must be submitted to the Journal for first rights of refusal. Authors are responsible for submitting papers of presentations directly to the Journal. Articles published in AJSM may not be published elsewhere without written permission from the publisher. Manuscripts should cite any other work by one or more of the co-authors that is relevant to the subject matter of the current submission or that used any of the same subjects, animals, or specimens being reported in the current submission. This includes manuscripts that are currently under preparation, are being considered by journals, are accepted for publication, or already published. In any of these cases, the relationship to the current submission should be made clear.

All review articles (such as systematic review, metaanalysis) submitted will be considered for the Current Concepts section. Authors with ideas for current concepts should contact the associate editor, Timothy Foster, MD, to find out if AJSM has recently published a review article on that topic of if there is a similar submission in progress. Contact Dr Foster at currentconcepts@ajsm.org to inquire about your idea or submit already completed papers directly to the journal at http://ajsm-submit.highwire.org.

SUBMISSIONS

Authors should register on our online submission site at http://ajsm-submit.highwire.org/ to submit manuscripts.

When manuscripts have been received by the editorial office, the corresponding author will be sent an acknowledgment giving an assigned manuscript number, which should be used with all subsequent correspondence for anything related to that particular manuscript.
The following items are required on submission:

1. Blinded manuscript including the abstract and figures legends. No identifying information should appear in the uploaded manuscript. Please remove author names, initials, and institutions. State or country names may be used, but do not include specific locations such as cities or regions.

2. Journal Contributor Publishing Agreement and AJSM Author Disclosure Statement. These forms are available for download from the author area of the submission site. The corresponding author must complete the forms and return them to AJSM by e-mail or upload them online as a PDF or Word file using the “upload legal documents” option. As an alternative to the AJSM disclosure form, authors may submit the ICMJE disclosure form *along with* the AJSM supplemental form available on our website.

3. A copy of the IRB or other agency approval (or waiver) if animal subjects or human subjects or tissues or health information were used. This information should be uploaded with the disclosure and publishing forms and not as a supplemental file.

Cover letter, acknowledgments, and suggested reviewers are optional. If a paper has more than 5 authors, a cover letter detailing the contributions of all authors should be included in the appropriate box on the submission page. Only those involved in writing the paper should be included in the author line. Others should be listed as a footnote or acknowledgment. While there is no limit on the number of authors, no more than 12 will be listed on the masthead of the published article; additional authors will be listed at the end of the article.

MANUSCRIPT FORMATS

Manuscript pages should be double-spaced with consecutive page numbers and continuous line numbers. The abstract should be included with the manuscript as well as being entered in the Metadata section (except for case reports, which do not require abstracts). Manuscripts should be 6000 words or fewer (including abstract and references). There are also limitations on figures, tables, and references; see guidelines below. The system handles most common word processing formats; however, Word and PDF are preferred.

MANUSCRIPT PREPARATION

Abstract

Abstracts should summarize the contents of the article in 350 words or less. The abstract should be structured in the following format:

Background: In one or two sentences, summarize the scientific body of knowledge surrounding your study and how this led to your investigation.
Hypothesis/Purpose: State the theory(ies) that you are attempting to prove or disprove by your study or the purpose if no hypothesis exists.
Study Design: Identify the overall design of your study. See list below.
Methods: Succinctly summarize the overall methods you used in your investigation. Include the study population, type of intervention, method of data collection, and length of the study.
Results: Report the most important results of your study. Only include positive results that are statistically

significant, or important negative results that are supported by adequate power. Report actual data, not just *P* values.

Conclusion: State the answer to your original question or hypothesis. Summarize the most important conclusions that can be directly drawn from your study.

Clinical Relevance: If yours was a laboratory study, describe its relevance to clinical sports medicine.

Key Terms: Include at least 4 key terms for indexing. When submitting an article, you will be asked to choose from a list of terms that are used for assigning reviewers. These terms can be used in the manuscript as well. The list can be found at http://ajsm-submit.highwire.org/submission/ editexpertise

What is known about the subject: Please state what is currently known about this subject to place your study in perspective for the reviewers.

What this study adds to existing knowledge: Please state what this study adds to the existing knowledge. The last two items are for reviewers only and are not included in the word count, but should appear at the end of the abstract in the uploaded text.

Study Designs

Meta-analysis: A systematic overview of studies that pools results of two or more studies to obtain an overall answer to a question or interest. Summarizes quantitatively the evidence regarding a treatment, procedure, or association.

Systematic Review: An article that examines published material on a clearly described subject in a systematic way. There must be a description of how the evidence on this topic was tracked down, from what sources and with what inclusion and exclusion criteria.

Randomized Controlled Clinical Trial: A group of patients is randomized into an experimental group and a control group. These groups are followed up for the variables / outcomes of interest.

Crossover Study Design: The administration of two or more experimental therapies one after the other in a specified or random order to the same group of patients.

Cohort Study: Involves identification of two groups (cohorts) of patients, one which did receive the exposure of interest, and one which did not, and following these cohorts forward for the outcome of interest.

Case-Control Study: A study that involves identifying patients who have the outcome of interest (cases) and patients without the same outcome (controls), and looking back to see if they had the exposure of interest.

Cross-Sectional Study: The observation of a defined population at a single point in time or time interval. Exposure and outcome are determined simultaneously.

Case Series: Describes characteristics of a group of patients with a particular disease or who have undergone a particular procedure. Design may be prospective or retrospective. No control group is used in the study, although the discussion may compare the results to other published outcomes.

Case Report: Similar to the case series, except that only one or a small group of cases is reported.

Descriptive Epidemiology Study: Observational study describing the injuries occurring in a particular sport.

Controlled Laboratory Study: An in vitro or in vivo investigation in which 1 group receiving an experimental treatment is compared to 1 or more groups receiving no treatment or an alternate treatment.

Descriptive Laboratory Study: An in vivo or in vitro study that describes characteristics such as anatomy, physiology, or kinesiology of a broad range of subjects or a specific group of interest. Authors should choose the design that best fits the study. The Editor will make the final determination of the study design and level of evidence based on the Center for Evidence Based Medicine guidelines.

Text

In general, follow the standard IMRAD (Introduction, Materials and Methods, Results, Discussion) format for writing scientific articles. The author is responsible for all statements made in the work, including copyeditor changes, which the author will have an opportunity to verify. Authors with limited fluency in English should have the paper reviewed or edited by a native English speaker to ensure clear presentation of the work. **Papers including human or animal subjects must include a statement of approval by appropriate agencies in the text, and a copy of the approval letter must be uploaded with the submission. If approval was not required, authors must upload a waiver statement from the appropriate agency.** For case reports, include a letter from the patient granting permission for his/her information to be included in the publication. Reports on surgery, except in rare instances, require a minimum follow-up of 2 years. Use generic names of drugs or devices. If a particular brand was used in a study, insert the brand name along with the name and location of the manufacturer in parentheses after the generic name when the drug or device is first mentioned in the text. Use metric units in measurements (centimeter vs inch, kilogram vs pound). Abbreviations should be used sparingly. When abbreviations are used, give the full term followed by the abbreviation in parentheses the first time it is mentioned in the text, such as femur-ACL-tibia complex (FATC). Use of a CONSORT flow diagram is recommended to illustrate the grouping and flow of patients in all clinical studies, whether randomized clinical trials or otherwise. Statistical methods should be described in detail. Actual *P* values should be used unless less than .001. Reporting of 95% confidence intervals is encouraged.

Acknowledgment

Type the acknowledgments in the box provided on the submission page; do not include it in the manuscript. This information will be added to the accepted manuscript at the time of publication. Give credit to technical assistants and professional colleagues who contributed to the quality of the paper but are not listed as authors. Please briefly describe the contributions made by persons being acknowledged. **Note: anyone who has contributed to the preparation of the submitted text must be included on the author disclosure form, under Statement of Authorship, and disclosures included there.**

References

References should be double-spaced in alphabetical order and numbered according to alphabetical listing. Except for review articles, references should be limited to 60. If references are not in alphabetical order the uploaded file will be REJECTED and will have to be resubmitted with the references in the correct form. When author entries are the same, alphabetize by the first word of the title. In general, use the Index Medicus form for abbreviating journal titles and the *AMA Manual of Style* (10th ed) for format. *Note:* References must be retrievable.

Do not include in the reference list meeting presentations that have not been published. Data such as presentations and articles that have been submitted for publication but have not been accepted must be put in the text as unpublished data immediately after mention of the information (for example, "Smith and Jones (unpublished data, 2000) noted ..."). Personal communications and other references to unpublished data are discouraged. For review purposes, unpublished references that are closely related to the submitted paper or are important for understanding it should be uploaded as supplemental files.

References will be linked to Medline citations for the reviewers. Authors can include articles that are in Epublish mode. To ensure that these Epub references are linked correctly, please provide the PMID number from Medline at the end of the reference. For example: Emery CA, Meeuwisse WH. Injury rates, risk factors, and mechanisms of injury in minor hockey. *Am J Sports Med*. 2006 Jul 21; [Epub ahead of print] PMID: 16861577

Figures and Tables

Figures and tables should not exceed 3 journal pages. One journal page equals 1 large table or figure, 2 medium-sized tables or figures, or 4 small tables or figures. Medium-sized tables and figures will be a page width and half the length of the page; small tables and figures are 1-column width and take up half the length of the page or less. Any material that is submitted with an article that has been reproduced from another source (that is, has been copyrighted previously) must conform to the current copyright regulations. It is the author's responsibility to obtain written permission for reproduction of copyrighted material and for providing the editorial office with that documentation before the material will be reproduced in the Journal. **All image files for figures should be labeled with the Figure number (label each part if figures include multiple parts, eg, 2A, 2B).** Be sure to include figure legends in the text. The figure legend should include descriptions of each figure part and identify the meaning of any symbols or arrows. Terms used for labels and in the legend must be consistent with those in the text. Color will be used in the Journal where needed (eg, histology slides or surgical photographs). All other figures, such as bar graphs and charts, should be submitted in black and white. Figures for papers accepted for publication must meet the image resolution requirements of the publisher, Sage Publications. Files for line-based drawings (no grayscale) should ideally be submitted in the format they were originally created; if submitting scanned versions, files should be 1200 dots per inch (dpi). Color photos should be submitted at 600 dpi and black-and-white photos at 300 dpi. Charts and graphs can be submitted in the original form created (eg, Word, Excel, or PowerPoint). Photographs or scanned drawings embedded in Word or PowerPoint are not acceptable for publication. If figures are embedded in the submitted manuscript for ease of reading they should also be submitted as separate files for use in the publication process.

All photographs of patients that disclose their identity must be accompanied by a signed photographic release granting permission for their likeness to be reproduced in the article. If this is not provided, the patient's eyes must be occluded to prevent recognition.

For tables, the system accepts most common word processing formats. Tables should be numbered consecutively and have a title that describes the content and purpose of the table. Tables should enhance, not duplicate, information in the text.

Videos

Use of supplementary video is encouraged. Videos may be submitted with a manuscript and, if approved by the editor, will be posted online with the article when published. Video submission is strongly encouraged for manuscripts reporting surgical, examination, or exercise techniques or injury mechanisms. For more information about the format requirements for videos, please review the Video Format Guide.

For detailed information pertaining to copyright and permissions requirements, view the Video Permission and Fair Use Quick Guide. For videos with identifiable subjects, subjects will need to sign the Audio-Visual Likeness Release form. It is the author's responsibility to submit signed release forms, if necessary, for each video.

ACCEPTED MANUSCRIPTS

Once an article is accepted and typeset, authors will be required to carefully read and correct their manuscript proofs that have been copyedited by the publisher. Any extensive changes made by authors on the proofs will be charged to authors at the rate of $2 a line. Authors are responsible for ordering reprints of their articles; a reprint order form is provided with the page proofs. Completed articles will be published on our website before print publication.

NIH-Supported Studies

Authors of studies funded by grants from the National Institutes of Health can deposit a copy of their accepted final peerreviewed manuscript and associated figure/table files (pretypeset versions) to the NIH database after a 12-month embargo period from the time their article is published in AJSM.

Capítulo 3 – American Journal of Dentistry

Information for Authors

The **AMERICAN JOURNAL OF DENTISTRY** is published six times a year in February, April, June, August, October and December by *Mosher & Linder, Inc.*

The **AJD** invites submission of research manuscripts and reviews related to the clinical practice of dentistry. Manuscripts are considered for publication with the understanding that they have not been published elsewhere in any form or any language, are submitted solely to the **AJD**, and if accepted for publication in the **AJD**, they will not be published elsewhere in the same form or in any other language, without the consent of the Editor. Manuscripts are reviewed by at least two referees.

Statements and opinions expressed in the articles and com-munications herein are those of the author(s) and not necessarily those of the Editor, Managing Editor, Editorial Board members or publisher of the **AMERICAN JOURNAL OF DENTISTRY**.

All correspondence from the Editorial Office will be made with the designated Corresponding Author unless otherwise specified in a letter by the authors.

PREPARATION OF MANUSCRIPTS. Papers should be written in proper American English, double spaced, with liberal margins, and **only submitted by E-mail to the Editor**, with the text and tables in Microsoft Word files and illustrations in JPEG image format.

Papers reporting results of original research should be divided into Introduction, Materials and Methods, Results, Discussion, Acknowledgements (if any), and References.

CLINICAL RESEARCH PAPERS. Need to follow the CONSORT Statement (Needleman I, *et al*. *Am J Dent* 2008;21: 7-12).

DISCLOSURE STATEMENT. The *American Journal of Dentistry* is instituting a policy to disclose conflicts of interest, as well as sponsorship of studies published in the Journal. Please provide information regarding any conflict of interest relationships of all authors, or state that each author has no conflict.

Examples of common financial relationships include: employment, consultancies, stock ownership, honoraria, and paid expert testimony. You can read more about other potential conflict of interests and the general policy at: http://www.nlm.nih.gov/pubs/factsheets/ supplements.html and http:// www.icmje.org/#conflicts

COPYRIGHT RELEASE. The following statement, signed by all authors, should accompany all manuscripts:

"All manuscript's copyright ownership is transferred from the author(s) of the article (title of article), to the American Journal of Dentistry in the event the work is published. The manuscript has not been published in any form or any language and is only submitted to the American Journal of Dentistry".

TITLE PAGE should include the title of the manuscript, all authors' full names and degrees, affiliations to institution or private practice, designation and address of corresponding author, telephone and fax numbers and e-mail address.

Disclosure statement

ABSTRACT PAGE should follow the title page and only contain: the title of the manuscript, the abstract and the clinical significance sections. On the abstract page, the name(s) of the author(s) should not appear. The abstract should have the following sections: Purpose, Methods, and Results.

CLINICAL SIGNIFICANCE. As a separate sentence after the abstract, a short statement should highlight the clinical significance of the manuscript.

REFERENCES. All references and only those cited in the text should appear in the list of references. They should be numbered consecutively as they appear in the text of the paper. Reference formatting programs should not be used.

When a paper cited has three or more authors, it should appear in the text thus: Gwinnett *et al*.1 In the Reference section, article references must include the names and initials of all the authors, the full title of the paper, the abbreviated title of the journal, year of publication, the volume number, and first and last page numbers, *e.g.*:

Journals:

1. Thornton JB, Retief DH, Bradley EA. Marginal leakage of two glass ionomer cements: Ketac-Fil and Ketac-Silver. *Am J Dent* 1988; 1: 35-38.

Abstracts:

2. Alpeggiani M, Gagliani M, Re D. Operator influence using adhesive systems: One bottle *vs.* multi bottles. *J Dent Res* 1998;77: 942 (Abstr 2487).

Online abstracts:

3. Bayne SC, Wilder Jr AD, Perdigão J, Heymann HO, Swift EJ. 4-year wear and clinical performance of packable posterior composite. *J Dent Res* 2003:86 (Sp Is A): (Abstr 0036).

Papers in the course of publication should only be entered in the references if they have been accepted for publication by a journal and then given in the standard manner in the text and in the list of references with the journal title, accompanied by "In press," *e.g.*:

3. Crim GA, Abbott LJ. Effect of curing time on marginal sealing by four dentin bonding agents. *Am J Dent*, In press.

Book and monograph references should include author, title, city, publisher, year of publication, and page numbers, *e.g.*:

4. Malone WFP, Koth DL. *Tylman's theory and practice of fixed prosthodontics*. St. Louis: Ishiyaku Euro-America, 1989; 110-123.

5. Ripa LW, Finn SB. The care of injuries to the anterior teeth of children. In: Finn SB. *Clinical pedodontics*. 4th ed, Philadelphia: WB Saunders, 1973; 125.

Personal communications should only appear in paren-theses in the text and not in the list of references.

ILLUSTRATIONS. Illustrations should be numbered, provided with suitable legends, and kept to the minimum essential for proper presentation of the results. Color illustrations will be published at the authors’ expense. Contact the Managing Editor at (954) 888-9101 or amjdent@amjdent.com.

Legends are required for all illustrations and should be typed as a group on a separate page. For photomicrographs, legends must specify original magnification and stain (if used).

TABLES should be logically organized and should supplement the information provided in the text. Each table should be typed on a separate page with the number, title and footnotes. Tables should be kept to the minimum essential for proper presentation of the results.

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6/09

Capítulo 5 – Revista Clínica – International Journal of Brazilian Dentistry

NORMAS PARA PUBLICAÇÃO DE ARTIGOS

Please, read the Instructions for Authors at the site www.revistaclinica.com.br A revista Clínica - International Journal of Brazilian Dentistry é dirigida à classe odontológica e a profissionais de áreas afins. Destina-se à publicação de artigos de investigação científica, relatos de casos clínicos e de técnicas, e revisões da literatura de assuntos de significância clínica, com periodicidade trimestral. As normas, principalmente na parte de referência da revista, estão baseadas no Uniform Requirements for Manuscripts Submitted to Biomedical Journals: Writing and Editing for Biomedical Publication, do International Committee of Medical Journal Editors (Grupo de Vancouver). N Engl J Med. 1997;336:309-16. Essas normas foram atualizadas em outubro de 2004 e estão descritas no site http://www.icmje.org.

NORMAS GERAIS

1) Os manuscritos enviados para publicação deverão ser inéditos, não sendo permitida a sua apresentação simultânea a outros periódicos. Caso não sejam seguidas as normas da revista, o manuscrito será devolvido para as devidas adaptações. A revista Clínica reserva-se todos os direitos autorais do trabalho publicado, inclusive de versão e tradução, permitindo-se a sua posterior reprodução como transcrição, com a devida citação da fonte.
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Os manuscritos podem ser submetidos em três formatos:
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b) Relato de casos clínicos e de técnicas: título em português e inglês (máximo de 12 palavras), nomes, titulação e filiação institucional dos autores, endereço completo do autor principal (apenas na folha de rosto), resumo (máximo de 10 linhas), palavras-chave, introdução, revisão da literatura, relato do caso, discussão, conclusões ou considerações finais, abstract (máximo de 10 linhas), keywords, referências, agradecimentos e legenda das figuras;
c) Revisão da literatura: título em português e inglês (máximo de 12 palavras), nomes, titulação e filiação institucional dos autores, endereço completo do autor principal (apenas na folha de rosto), resumo (máximo de 10 linhas), palavras-chave, significância clínica (máximo de 10 linhas), introdução, revisão da literatura, discussão, conclusão, abstract (máximo de 10 linhas), keywords, referências, agradecimentos e legenda das figuras (caso houver).

REFERÊNCIAS

As referências (estilo de Vancouver) deverão ser numeradas consecutivamente, na ordem em que aparecem no texto pela primeira vez, excluindo-se, conseqüentemente, o nome do autor no texto. Todos os autores citados no texto, nas tabelas e nas figuras deverão constar nas referências conforme a numeração progressiva deles no texto.

EXEMPLOS DE REFERÊNCIAS

De um a seis autores

Lodish H, Baltimore D, Berk A, Zipursky SL, Matsudaira P, Darnell J. Molecular cell biology. 3rd ed. New York: Scientific American; 1995.

Com mais de seis autore

Liebler M, Devigus A, Randall RC, Burke FJ, Pallesen U, Cerutti A, et al. Ethics of esthetic dentistry. Quintessence Int. 2004 Jun;35(6):456-65.

Livro

Marzola C. Técnica exodôntica. 3a ed. rev. ampl. São Paulo: Pancast; 2001.

Capítulo de livro

Soviero C, Garcia RS. Músculos da mímica facial. In: Oliveira MG, organizadora. Manual de anatomia da cabeça e do pescoço. 3a ed. Porto Alegre: EDIPURS; 1998. p. 66-73.

Sem indicação de autoria

Council on Drugs. List no. 52. New names. JAMA. 1966 Jul 18;197(3):210-1.

Instituição como autor

Conselho Nacional de Saúde(BR). Resolução no 196/96, de 10 de outubro de 1996. Dispõe sobre as diretrizes e normas regulamentares de pesquisa envolvendo seres humanos. Brasília: O Conselho; 1996.

Editor como autor

Murray JJ, editor. O uso correto de fluoretos na saúde pública. São Paulo: Santos;1992.

Trabalho em congresso

Lorenzetti J. A saúde no Brasil na década de 80 e perspectivas para os anos 90. In: Mendes NTC, coordenadora. Anais do 41º Congresso Brasileiro de Enfermagem; 1989 Set 2-7; Florianópolis, Brasil. Florianópolis: ABEn-Seção SC; 1989. p. 92-5.

Dissertação e tese

Tavares R. Avaliação da resistência de fundações de amalgama, através da tração de coroas totais metálicas [dissertação]. Florianópolis SC):Programa de Pós-Graduação em Odontologia/UFSC; 1988.

Documentos legais

Brasil. Portaria no 569, de 1 de junho de 2000. Institui o Programa de Humanização no Pré-natal e Nascimento. Diário Oficial da República Federativa do Brasil, 8 jun 2000. Seção 1.

Material não publicado

Tian D, Araki H, Stahl E, Bergelson J, Kreitman M. Signature of balancing selection in Arabidopsis. Proc Nath Acad Sci U S A. In press 2002.

Artigo padrão

Kidd EA. How 'clean' must a cavity be before restoration? Caries Res. 2004 May-Jun;38(3):305-13.

Artigo com número e suplemento

Fitzpatrick KC. Regulatory issues related to functional foods and natural health products in Canada: possible implications for manufacturers of conjugated linoleic acid. Am J Clin Nutr. 2004 Jun;79(6 Suppl):1217S-1220S.

Artigo sem número e com volume

Ostengo Mdel C, Elena Nader-Macias M. Hydroxylapatite beads as an experimental model to study the adhesion of lactic Acid bacteria from the oral cavity to hard tissues. Methods Mol Biol. 2004;268:447-52.

Artigo sem número e sem volume

Browell DA, Lennard TW. Inmunologic status of the cancer patient and the effects of blood transfusion on antitumor responses. Curr Opin Gen Surg. 1993:325-33.

Artigo indicado conforme o caso

Collins JG, Kirtland BC. Experimental periodontics retards hamster fetal growth [abstract]. J Dent Res. 1995;74:158.

Artigo de jornal

Tynan T. Medical improvements lower homicide rate:study sees drop in assault rate. The Washington Post. 2002 Aug 12; Sect. A:2 (col.4).

Material eletrônico

Abood S. Quality improvement initiative in nursing homes: the ANA acts in an advisory role. Am J Nurs [serial on the Internet]. 2002 Jun [cited 2002 Aug 12];102(6):[about 3 p.]. Available from: http://www.nursingworld.org/AJN/2002/june/wawatch.htm.

Foley KM, Gelband H, editors. Improving palliative care for cancer [monograph on the Internet]. Washington: National Academy Press; 2001[cited 2002 Jul 9]. Available from: http://www.nap.edu/books/0309074029/html/. Anderson SC, Poulsen KB. Anderson's electronicatlas of hematology [CDROM]. Philadelphia: Lippincott Willians &Wilkins; 2002.

OBSERVAÇÕES ADICIONAIS

A referência comercial dos equipamentos, instrumentos e materiais citados deve ser composta respectivamente por modelo, marca e país fabricante, separados por vírgula e entre parênteses.

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