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AVALIAÇÃO DAS ALTERAÇÕES MORFOLÓGICAS DO FORAME APICAL APÓS AMPLIAÇÃO FORAMINAL: *UMA REVISÃO SISTEMÁTICA*

Faculdade de Odontologia
Universidade Federal de Minas Gerais
Belo Horizonte
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Dissertação apresentada ao Colegiado de Pós-Graduação em Odontologia da Faculdade de Odontologia da Universidade Federal de Minas Gerais, como requisito parcial à obtenção do grau de Mestre em Odontologia - área de concentração em Endodontia.

Orientadora: Prof.ª Dr.ª Ana Cecília Diniz Viana
Coorientador: Prof. Dr. Warley Luciano Fonseca Tavares

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FOLHA DE APROVAÇÃO

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Aprovada em 22 de julho de 2022, pela banca constituída pelos membros:

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“Não basta ensinar ao homem uma especialidade. Porque se tornará assim uma máquina utilizável, mas não uma personalidade. É necessário que adquira um sentimento, um senso prático daquilo que vale a pena ser empreendido, daquilo que é belo, do que é moralmente correto.”

Albert Einstein

RESUMO

Este trabalho de revisão sistemática propôs-se a avaliar as alterações morfológicas do forame apical após procedimento de ampliação foraminal. Foi realizada busca eletrônica nas bases de dados *PubMed/Medline*, *Scopus*, *Web of Science*, SciELO, Embase, Google Acadêmico e listas de referência até abril de 2022. Apenas estudos *ex vivo* avaliando a influência do alargamento foraminal nas alterações morfológicas do forame apical foram incluídos. Estudos sem um grupo controle ou texto completo disponível foram excluídos. Deformação foraminal e aumento de área do forame foram considerados os desfechos primários. A avaliação do risco de viés foi realizada de acordo com uma lista de verificação modificada do *Joanna Briggs Institute*. Setecentos e dois estudos foram recuperados, dos quais treze eram elegíveis para análise qualitativa. A maioria dos estudos utilizou molares superiores ou inferiores com canais radiculares curvos e sistemas rotatórios e reciprocantes para instrumentação. O comprimento de trabalho determinado pelos estudos incluídos variou de dois milímetros aquém a um milímetro além do forame apical. Em relação à deformação foraminal, dos estudos incluídos nesta revisão, oito encontraram aumento da deformação do forame após ampliação foraminal, enquanto cinco não observaram influência significativa. Entre oito estudos que avaliaram a área foraminal, todos encontraram aumento da área após ampliação foraminal. Dados insuficientes para paredes tocadas/intocadas pelos instrumentos endodônticos e formação de microtrincas dentinárias foram observados. Um baixo risco de viés foi encontrado. Dentro das limitações desta revisão, nota-se que a ampliação foraminal durante o preparo do canal radicular parece aumentar a deformação e a área do forame apical, especialmente quando o comprimento de trabalho excede o limite do forame maior em, pelo menos, um milímetro. No entanto, não foi possível concluir se existe um protocolo conservador, porém eficaz, para ampliação foraminal, devido à grande heterogeneidade metodológica dos estudos. Futuras investigações com metodologias padronizadas são encorajadas a fim de se fornecer evidências mais robustas.

Palavras-chave: Endodontia. Tratamento do canal radicular. Preparo de canal radicular. Ápice dentário. Forame apical. Revisão sistemática.

ABSTRACT

Evaluation of morphological alterations of apical foramen after foraminal enlargement: a systematic review

This systematic review aimed to evaluate the morphological alterations of the apical foramen after foraminal enlargement procedure. Electronic searches were performed in PubMed/Medline, Scopus, Web of Science, SciELO, Embase, Google Scholar databases and reference lists until April 2022. Only ex vivo studies evaluating the influence of foraminal enlargement on morphological changes of the apical foramen were included. Studies without a control group or full text available were excluded. Foraminal deformation and increased area were considered the primary outcomes. The risk of bias assessment was performed according to a modified Joanna Briggs Institute checklist. Seven hundred two studies were retrieved, of which thirteen were eligible for qualitative analysis. Most studies used maxillary or mandibular molars with curved root canals and rotary and reciprocating systems for instrumentation. The working length determined by the included studies ranged from two millimeters short to one millimeter beyond the apical foramen. Regarding foraminal deformation, of the studies included in this review, eight found an increase in foramen deformation after foraminal enlargement, while five did not observe a significant influence. Among eight studies that evaluated the foraminal area, all found an increase in the area after foraminal enlargement. Insufficient data for touched/untouched cemental walls by endodontic instruments and formation of dentin microcracks were observed. A low risk was found in the risk of bias analysis of eligible studies. Within the limitations of this review, it is noted that foraminal enlargement during root canal preparation seems to increase the deformation and area of the apical foramen, especially when the working length exceeds the limit of the greater foramen by at least one millimeter. However, it was not possible to conclude whether there is a conservative but effective protocol for foraminal enlargement due to the great methodological heterogeneity of the studies. Future investigations with standardized methodologies are encouraged in order to provide more robust evidence.

Keywords: Endodontics. Root Canal Therapy. Root Canal Preparation. Tooth Apex. Apical Foramen. Systematic Review.

LISTA DE ILUSTRAÇÕES

LISTA DE QUADROS

LISTA DE ABREVIATURAS E SIGLAS

CT	Comprimento de trabalho
CDC	Cemento-dentina-canal
EDTA	Ácido Etilenodiaminotetracético
JBI	*Joanna Briggs Institute*
IAF	*Initial apical file*
Micro-CT	*Micro-computed tomography*
NaOCl	Hipoclorito de sódio
NiTi	Níquel-titânio
OSF	*Open Science Framework*
PTN	*ProTaper Next*
SCR	Sistema de canais radiculares
SEM	*Scanning electron microscopy*
SPSS	*Statistical Package for the Social Science*
WL	*Working length*

SUMÁRIO

1 CONSIDERAÇÕES INICIAIS

O preparo químico-mecânico é uma importante etapa do tratamento endodôntico, proporcionando, no caso de polpas infectadas, a eliminação de microrganismos e seus produtos do canal radicular a um nível compatível com o reparo dos tecidos perirradiculares, além da remoção do tecido pulpar necrótico que pode servir como substrato para a reinfecção (PRADA *et al*., 2019; SIQUEIRA; RÔÇAS, 2008; SIQUEIRA JUNIOR *et al*., 2018).

Para o efetivo preparo químico-mecânico do sistema de canais radiculares (SCR), a determinação de um comprimento de trabalho (CT) adequado é fundamental. A instrumentação aquém do CT apropriado pode deixar remanescentes de tecido necrótico (SELTZER *et al*., 2004; SIQUEIRA JUNIOR *et al*., 2018), enquanto a instrumentação além deste ponto poderia agravar a resposta inflamatória nos tecidos periapicais (HOLLAND *et al*., 2005; RICUCCI; LANGELAND, 1998; SELTZER *et al*., 1968), além de favorecer a extrusão apical de material obturador (ALBUQUERQUE *et al*., 2020).

Tradicionalmente, preconizava-se que a instrumentação dos canais deveria se restringir ao interior do canal dentinário, ou ao nível da constrição apical. Na prática, a medida para um comprimento de trabalho de meio a um milímetro aquém do ápice radiográfico era considerada aceitável, apesar de não se conseguir determinar, desta maneira, uma medida exata da localização do limite cemento-dentina-canal (CDC), ou da região de menor diâmetro apical (RICUCCI, 1998).

Estudos demonstraram que em um CT de um milímetro aquém do forame maior, há redução de endotoxinas e bactérias cultiváveis, porém em nenhum caso, houve a completa descontaminação do canal radicular (MACHADO *et al*., 2019; MARTINHO *et al*., 2014). Adicionalmente, outros trabalhos observaram que a instrumentação ao nível do forame maior, ou além dele, otimiza a redução microbiana no SCR, em comparação ao preparo mecânico aquém do forame, especialmente quando há um aumento no diâmetro do instrumento durante o preparo apical (SACOMANI *et al*., 2021; YADAV *et al*., 2014).

Essa concepção de se realizar a instrumentação do canal cementário não é tão recente. Na década de 1970, com a preocupação de se evitar remanescentes microbianos no interior dos canais radiculares, Butler (1970) levantou a hipótese de que para assegurar o desbridamento adequado quando o tecido necrótico ocupa a porção apical do canal radicular, o instrumento endodôntico deveria penetrar através do forame apical. Da mesma forma, para Schilder (1974), nos casos de necrose pulpar, um desbridamento apenas o suficiente para garantir a limpeza da região foraminal poderia ser realizado, porém evitando-se a remoção excessiva de dentina apical e cemento. Desde então, as discussões em relação a um comprimento de trabalho ideal nunca cessaram, e um consenso entre pesquisadores não foi alcançado (RICUCCI, 1998; RICUCCI; LANGELAND, 1998; SOUZA, 2006).

Somando-se à definição de um comprimento ótimo de trabalho, a determinação de um alargamento conveniente da região apical deve ser analisada, com a finalidade de se potencializar a limpeza e desinfecção dos canais radiculares, minimizando-se os riscos do procedimento (USMAN; BAUMGARTNER; MARSHALL, 2004). Alguns trabalhos (MOORE; FITZ-WALTER; PARASHOS, 2009; SILVA *et al*., 2016; TAN; MESSER, 2002) sustentam-se no critério descrito por Grossman, Oliet e Rio (1988), no qual se expande o canal em, pelo menos, três diâmetros (do padrão ISO para instrumentos endodônticos) maiores em relação ao instrumento que primeiro se ajusta ao CT. A convicção é que um maior alargamento proporciona menor porcentagem de paredes do canal que não foram tocadas pelo instrumento, levando a uma melhor limpeza e desbridamento da região apical (STRINGHETA *et al*., 2021; TAN; MESSER, 2002). No entanto, há de se atentar que a determinação clínica do diâmetro anatômico do canal no CT é imprecisa, e o pré-alargamento dos terços médio e cervical favorece tal propósito (BARROSO *et al*., 2005).

Associando-se, portanto, essas duas ideias: (1) a de se determinar um comprimento de trabalho que alcance o canal cementário, (2) com um aumento do diâmetro apical que garanta a limpeza adequada da região, tem-se o conceito da ampliação foraminal (SOUZA FILHO, 2015). Todavia, não se observa, na literatura, um protocolo bem definido para a realização deste procedimento, nem em relação ao quanto se deve ampliar, nem em relação ao comprimento ideal de trabalho: ao nível do forame maior (BRANDÃO *et al*., 2019; KURNAZ, 2020; YAYLALI; TEKE; TUNCA, 2017), ou além dele (MACHADO *et al*., 2021; SOUZA FILHO; BENATTI; DE ALMEIDA, 1987).

Ademais, os efeitos que o alargamento do forame apical e um desvio de sua anatomia original poderiam ocasionar no tratamento endodôntico devem ser analisados. Estudos *ex vivo* demonstram que o selamento apical após obturação dos canais radiculares não seria afetado pela ampliação foraminal, mesmo na ocorrência de deformações do forame apical (SILVA *et al*., 2016; SOUZA *et al*., 2021). Entretanto, uma maior extrusão de cimento obturador decorre da instrumentação do forame maior (ALBUQUERQUE *et al*., 2020).

A extrusão além ápice de microrganismos, quando se realiza o preparo apical ao nível do forame maior, mesmo com uma maior ampliação do seu diâmetro, também parece não apresentar diferença significativa, comparando-se à instrumentação convencional dos canais radiculares, em que se define o CT em um milímetro aquém de toda a extensão do canal radicular, segundo Teixeira *et al*. (2015).

Já a formação de microfissuras na superfície radicular, causada pela ampliação foraminal, é controversa. Enquanto Adorno, Yoshioka e Suda (2011) e Liu *et al*. (2013) observaram que a sobreinstrumentação do canal radicular favorece a formação de microtrincas na superfície radicular, Vieira *et al*. (2020) não observaram tal desfecho.

Ainda que a instrumentação foraminal se mostre uma linha de pensamento para otimizar a limpeza, a desinfecção dos canais radiculares (SACOMANI *et al*., 2021) e o reparo dos tecidos perirradiculares (BRANDÃO *et al*., 2019; SOUZA FILHO; BENATTI; DE ALMEIDA, 1987) cada vez mais defendida e recomendada por pesquisadores (BEZERRA *et al*., 2021; LIMA; SOARES; SOUZA-FILHO, 2012; SOUZA FILHO, 2015; SOUZA *et al*., 2021; SOUZA, 2006), é preciso lembrar-se do princípio clássico de Schilder (1974) que buscava a manutenção do formato e posição do forame apical, e é necessário, portanto, compreender se e como a ampliação foraminal atua, em seus diferentes protocolos, na alteração morfológica do forame maior. Dessa forma, o objetivo do presente trabalho foi analisar, através de uma revisão sistemática da literatura, as alterações morfológicas do forame apical encontradas quando trabalhado pelos instrumentos endodônticos.

2 OBJETIVOS

2.1 Objetivo geral

Avaliar, através de uma revisão sistemática da literatura, as alterações morfológicas do forame apical, após ampliação foraminal.

2.2 Objetivos específicos

a) Analisar se a ampliação foraminal resulta em maior deformação do forame apical, em relação à instrumentação convencional;
b) Avaliar como o comprimento de trabalho influencia as alterações morfológicas do forame;
c) Associar as alterações morfológicas da região foraminal com o diâmetro do instrumento utilizado e o comprimento de trabalho determinado;
d) Avaliar outros fatores que possam influenciar esse processo.

3 METODOLOGIA EXPANDIDA

3.1 Delineamento do estudo

O presente estudo compreende uma revisão sistemática da literatura, relatada de acordo com a lista de verificação *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA). Foi registrado um protocolo de pesquisa na plataforma *Open Science Framework* (OSF) (https://osf.io/bxmt9).

O formato "população, intervenção, comparação, resultado e desenho de estudo" (PICOS) foi usado para abordar a seguinte questão de pesquisa: "A ampliação foraminal influencia as mudanças morfológicas do forame apical?" A população do estudo (P) foi composta por dentes humanos extraídos submetidos ao preparo do canal radicular. A intervenção (I) explorada foi o preparo do canal radicular com ampliação foraminal; a comparação (C) utilizada foi o preparo do canal radicular sem ampliação foraminal ou instrumentação com tamanho de ponta de instrumento semelhante ao tamanho do forame. O desfecho primário (O) avaliado foi a deformação e a área do forame apical. Os desfechos secundários foram áreas tocadas ou intocadas pelos instrumentos e formação de microtrincas dentinárias. O desenho de estudo (S) elegível foi estudos *ex vivo*.

3.2 Critérios de elegibilidade

Foram incluídos, nesta revisão sistemática, os trabalhos que avaliaram alterações morfológicas do forame apical decorrentes da sua instrumentação, seguindo os seguintes critérios:

a) trabalhos que compararam tais alterações no mesmo comprimento de trabalho, porém com distintos diâmetros de ponta do instrumento nos grupos;

b) estudos que avaliaram o mesmo diâmetro de ponta de instrumentos endodônticos quando trabalhados em diferentes comprimentos de trabalho;

c) estudos que compararam tanto diâmetros de ponta, quanto comprimentos de trabalho diferentes;
d) estudos que tenham analisado as alterações do forame, com instrumentos trabalhando no mesmo comprimento de trabalho, com mesmo diâmetro de ponta, porém apresentando diferentes conicidades, resultando em diâmetro foraminal diferente;
e) trabalhos que consideraram um controle intragrupo, pré-ampliação foraminal, para analisar a deformação foraminal.

Por outro lado, os critérios de exclusão foram:
a) estudos que não relataram um parâmetro para comparação;
b) estudos de relato de caso;
c) estudos para os quais não foi possível obter o texto completo;
d) estudos com ausência do desfecho primário.

3.3 Estratégia de busca

As buscas foram realizadas nas bases de dados PubMed/MEDLINE, Scopus, Web of Science, SciELO, Embase e Cochrane Library para artigos publicados até abril de 2022. A literatura cinzenta foi consultada através do Google Scholar e buscas manuais foram realizadas na lista de referências dos artigos elegíveis. O quadro 1 apresenta a estratégia de busca utilizada para cada base de dados.

Quadro 1 - Estratégia de busca utilizada nas bases de dados eletrônicas

BASE DE DADOS	ESTRATÉGIA DE BUSCA
Medline/PubMed (http://www.ncbi.nlm.nih.gov/pubmed)	("apical enlargement"[All Fields] OR "apical preparation"[All Fields] OR "apical expansion"[All Fields] OR "apical widening"[All Fields] OR "apical debridement"[All Fields] OR "foraminal enlargement"[All Fields] OR "foraminal expansion"[All Fields] OR "foraminal widening"[All Fields] OR "foraminal debridement"[All Fields]) AND ("endodontal"[All Fields] OR "endodontic"[All Fields] OR "endodontical"[All Fields] OR "endodontically"[All Fields] OR "endodontics"[MeSH Terms] OR "endodontics"[All Fields] OR ("instrumentation"[MeSH Subheading] OR "instrumentation"[All Fields] OR "instrumentation s"[All Fields] OR "instrumentational"[All Fields] OR "instrumentations"[All Fields] OR "instrumention"[All Fields]) OR "root canal instrumentation"[All Fields] OR "root canal preparation"[All Fields] OR "root canal therapy"[All Fields] OR "root canal treatment"[All Fields]) AND ("morpholog*"[All Fields] OR "geometr*"[All Fields] OR ("alter"[All Fields] OR "alterated"[All Fields] OR "alteration"[All Fields] OR "alterations"[All Fields] OR "altered"[All Fields] OR "altering"[All Fields] OR "alters"[All Fields]) OR ("change"[All Fields] OR "changed"[All Fields] OR "changes"[All Fields] OR "changing"[All Fields] OR "changings"[All Fields]) OR "apical transportation"[All Fields] OR ("abnormalities"[MeSH Subheading] OR "abnormalities"[All Fields] OR "deformities"[All Fields] OR "congenital abnormalities"[MeSH Terms] OR ("congenital"[All Fields] AND "abnormalities"[All Fields]) OR "congenital abnormalities"[All Fields] OR "deformity"[All Fields] OR "deform"[All Fields] OR "deformabilities"[All Fields] OR "deformability"[All Fields] OR "deformable"[All Fields] OR "deformably"[All Fields] OR "deformation"[All Fields] OR "deformational"[All Fields] OR "deformations"[All Fields] OR "deformative"[All Fields] OR "deformed"[All Fields] OR "deforming"[All Fields] OR "deforms"[All Fields]) OR "apical displacement"[All Fields] OR ("crack cocaine"[MeSH Terms] OR ("crack"[All Fields] AND "cocaine"[All Fields]) OR "crack cocaine"[All Fields] OR "crack"[All Fields] OR "crack s"[All Fields] OR "cracked"[All Fields] OR "cracking"[All Fields] OR "crackings"[All Fields] OR "cracks"[All Fields]) OR "micro*"[All Fields] OR ("struct equ modeling"[Journal] OR "scan electron microsc"[Journal] OR "sem"[All Fields]))
Scopus (http://www.scopus.com/)	TITLE-ABS-KEY (("apical enlargement" OR "apical preparation" OR "apical expansion" OR "apical widening" OR "apical debridement" OR "foraminal enlargement" OR "foraminal expansion" OR "foraminal widening" OR "foraminal debridement") AND (endodontic OR instrumentation OR "root canal instrumentation" OR "root canal preparation" OR "root canal therapy" OR "root canal treatment") AND (morpholog* OR geometr* OR alteration OR change OR "apical transportation" OR deformation OR "apical displacement" OR crack OR micro* OR sem))
Cochrane (https://www.cochranelibrary.com/)	("apical enlargement" OR "apical preparation" OR "apical expansion" OR "apical widening" OR “apical debridement” OR "foraminal enlargement" OR "foraminal expansion" OR " foraminal widening" OR “foraminal debridement”) AND (endodontic OR instrumentation OR "root canal instrumentation" OR “root canal preparation” OR “root canal therapy” OR “root canal treatment”) AND (morpholog* OR geometr* OR alteration OR change OR “apical transportation” OR deformation OR “apical displacement” OR crack OR micro* OR SEM) in Title Abstract Keyword
Web of Science (https://clarivate.com/webofsciencegroup/solutions/web-of-science-core-collection/)	("apical enlargement" OR "apical preparation" OR "apical expansion" OR "apical widening" OR “apical debridement” OR "foraminal enlargement" OR "foraminal expansion" OR "foraminal widening" OR “foraminal debridement”) AND (endodontic OR instrumentation OR "root canal instrumentation" OR “root canal preparation” OR “root canal therapy” OR “root canal treatment”) AND (morpholog* OR geometr* OR alteration OR change OR “apical transportation” OR deformation OR “apical displacement” OR crack OR micro* OR SEM) (All Fields)
Embase (https://www.embase.com)	('apical enlargement' OR 'apical preparation' OR 'apical expansion' OR 'apical widening' OR 'apical debridement' OR 'foraminal enlargement' OR 'foraminal expansion' OR 'foraminal widening' OR 'foraminal debridement') AND (endodontic OR 'instrumentation'/exp OR instrumentation OR 'root canal instrumentation' OR 'root canal preparation'/exp OR 'root canal preparation' OR 'root canal therapy'/exp OR 'root canal therapy' OR 'root canal treatment') AND (morpholog* OR geometr* OR alteration OR 'change'/exp OR change OR 'apical transportation' OR 'deformation'/exp OR deformation OR 'apical displacement' OR 'crack'/exp OR crack OR micro* OR 'sem'/exp OR sem)
Scielo (https://scielo.org/en/)	("apical enlargement" OR "apical preparation" OR "apical expansion" OR "apical widening" OR “apical debridement” OR "foraminal enlargement" OR "foraminal expansion" OR " foraminal widening" OR “foraminal debridement”) AND (endodontic OR instrumentation OR "root canal instrumentation" OR “root canal preparation” OR “root canal therapy” OR “root canal treatment”) AND (morpholog* OR geometr* OR alteration OR change OR “apical transportation” OR deformation OR “apical displacement” OR crack OR micro* OR SEM)
Google Scholar (https://scholar.google.com/)	(“foraminal enlargement” OR “foramen enlargement” OR “foraminal debridement” OR “foraminal widening”) AND (endodontic OR "root canal therapy") AND (morpholog* OR alteration OR “apical transportation” OR deformation OR micro* OR SEM)

Fonte: Da autora, 2022.

3.4 Seleção dos estudos

Dois revisores foram calibrados para a realização da seleção dos estudos incluídos nesta revisão (I.F.A.M. e G.C.F.). Para isso, foi realizada uma busca prévia na base de dados PubMed. Os revisores selecionaram, a partir de título e resumo aqueles trabalhos que seriam potencialmente elegíveis para o presente estudo. Foi realizado o teste *kappa* de Cohen através do *software* estatístico SPSS (Statistical Package for the Social Science 19.0; IBM Corp, Armonk, NY), que deveria resultar em um índice superior a 0,80. Caso um índice menor fosse obtido, uma discussão entre os revisores e um *expert* seria realizada, e o processo de calibração executado novamente. Com a obtenção de um índice superior a 0,80, a busca nas outras bases prosseguiria.

A seleção dos estudos foi realizada por dois revisores de forma independente (I.F.A.M. e G.C.F.), em duas etapas: na primeira etapa, trabalhos potencialmente elegíveis foram selecionados através da leitura de seus títulos e resumos; em uma segunda etapa, os revisores realizaram a leitura do texto completo. Aqueles que cumpriam os critérios de elegibilidade foram incluídos nesta revisão.

Discrepâncias durante as etapas foram resolvidas por meio de uma discussão. Quando as divergências persistiram, um terceiro revisor (A.H.R.P.) foi consultado.

3.5 Modelo experimental

Um revisor (I.F.A.M.) realizou a extração dos dados dos trabalhos incluídos, que foram revisados por um segundo autor (A.C.D.V.). Foram recuperados os seguintes dados: sobrenome do primeiro autor, ano de publicação, modelo experimental, tamanho da amostra, grupos e protocolo experimental. Também foram coletados dados sobre a análise como métodos de avaliação e os principais achados do estudo.

Dados indisponíveis foram classificados como não informados.

3.6 Risco de viés

O risco de viés dos estudos selecionados foi avaliado de forma independente por dois revisores, em conformidade com uma versão modificada do *Joanna Briggs Institute Critical Appraisal Checklist for Experimental Studies* (AMINOSHARIAE; KULILD, 2015; DOS REIS-PRADO *et al*., 2021; YAYLALI; KECECI; UREYEN KAYA, 2015). Os itens incluídos na lista de verificação foram: objetivo claramente declarado, justificativa do tamanho da amostra, randomização da amostra, alocação cega do tratamento, possibilidade de comparação entre os grupos controle e tratamento, equivalência inicial dos grupos controle e tratamento, descrição clara do preparo do canal radicular, medição método, padronização de medidas e análise estatística. Cada item foi pontuado por meio de uma escala de 2 pontos: 0, não relatado ou relatado inadequadamente; 1, relatado e adequado. Dúvidas e discrepâncias entre os dois pesquisadores foram discutidas até a obtenção de um consenso. Quando necessário, um terceiro investigador foi consultado.

4 ARTIGO

O artigo com título "***Evaluation of morphological alterations of the apical foramen after foraminal enlargement: A systematic review of ex vivo studies***" apresentado a seguir[1], foi submetido ao periódico *Clinical Oral Investigations,* ISSN eletrônico: 1436-3771.

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[1] Artigo apresentado no idioma inglês, formatado conforme as normas da revista Clinical Oral Investigations.

Evaluation of morphological alterations of the apical foramen after foraminal enlargement: A systematic review of *ex vivo* studies

Abstract

Objective To evaluate morphological alterations of the apical foramen after foraminal enlargement through a systematic review.

Materials and Methods An electronic search was conducted (PubMed/Medline, Scopus, Web of Science, SciELO, Embase, Google Scholar and reference lists) until April 2022. E*x vivo* studies evaluating influence of foraminal enlargement in the morphologic changes of apical foramen were included. Studies without a control group or available full text were excluded. Foraminal deformation and area increase were considered as primary outcomes. Risk-of-bias assessment was performed according to a modified Joanna Briggs Institute's Checklist.

Results From 702 studies retrieved, 13 were eligible. Most studies used maxillary or mandibular molars curved root canals, and rotary and reciprocating systems for instrumentation ranging from – 2 mm to + 1.5 mm to the apex. Regarding foraminal deformation, eight, of 13 studies, found increased major foramen deformation after foraminal enlargement. Among eight studies that evaluated foraminal area, all found increased area after foraminal enlargement. Insufficient data for touched/untouched walls by instruments and dentinal microcrack formation was observed. A low risk of bias was found.

Conclusions Foraminal enlargement during root canal preparation seems to increase deformation and major apical foramen area. Future investigations with standardized methodologies are encouraged.

Clinical relevance An increased foraminal surface area was observed due to apical enlargement, which in cases of apical periodontitis can optimize root canal disinfection. Conversely, care must be taken when opting for a foraminal enlargement instrumentation technique, regarding ensuring a good adaptation of the main gutta percha cone, in order to prevent overflow or failures in filling material.

Keywords Apical foramen, endodontics, root canal therapy, root canal preparation, tooth apex, systematic review

Introduction

Chemical-mechanical preparation is an important step in endodontic treatment, which aims to eliminate microorganisms and their products from the root canal system in order to promote repair of periradicular tissues. In addition, this procedure aims at removing necrotic pulp tissue that can serve as a substrate for reinfection [1–3]. To achieve an effective chemical-mechanical preparation of the root canal system, the determination of an adequate working length (WL) is essential. Instrumentation below the appropriate WL can leave remnants of necrotic tissue [2, 4], in which can maintain endodontic infection. Conversely, instrumentation beyond the apical foramen might exacerbate the inflammatory response in the periodontal tissue [5–7] and result in apical extrusion of debris and filling materials [8].

Traditionally, it was recommended that root canal instrumentation should be restricted to the interior of the dentinal canal. In practice, a WL of 0.5 mm to 1 mm short of the radiographic apex is considered acceptable, although it might be not possible to exactly determine the location of the cementum-dentin junction [9]. While some authors suggest that the penetration of an endodontic instrument through the apical foramen is necessary for an adequate root canal cleaning due to the presence of necrotic tissue occupying the apical portion [10–12], other point out the importance of avoiding the excessive removal of apical dentin and cementum [6, 13]. Hence, a consensus among studies regarding the most ideal WL has not been reached yet [6, 9, 14].

Additionally, assessment of the most appropriate apical foramen enlargement should be considered, in order to enhance root canals cleaning and disinfection, minimizing concerns associated with this procedure, such as foramen deviation [15, 16], dentinal microcracks [15, 17], extrusion of microorganisms beyond the apex [18] and filling materials [8]. According to some studies [16, 19–21] and based on the criteria described by Grossman [22], apical enlargement is related to the expansion of the canal by at least three diameters (of the ISO standard for endodontic instruments) larger than the initial apical file (IAF) (first file that binds the foramen in the WL). A similar concept can be also applied to perform foraminal enlargement [16, 21]. However, it should be noted that the clinical determination of the root canal anatomical diameter in the WL is imprecise, and the middle and cervical thirds pre-enlargement may favor this purpose [23]. However, there is no well-defined protocol for performing foraminal enlargement in the literature, neither in relation to how much to expand, nor to the ideal WL. Thus, the objective of the present study was to evaluate, through a systematic review, the morphological alterations of the apical foramen after foraminal enlargement, through the assessment of *ex vivo* studies.

Materials and Methods

Protocol

The present systematic review was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist [24]. A research protocol was registered in the Open Science Framework (OSF) register (https://osf.io/bxmt9) [25].

Eligibility criteria

The inclusion criteria were: (1) studies that evaluated morphological alterations of the foramen using instruments with the same tip diameter at different WL, and (2) studies that compared instruments with different tip diameter and similar WL. Exclusion criteria were as follows: (1) studies without a comparison group; (2) case report studies; (3) studies for which the full text was unavailable; (4) studies that assessed only the secondary outcomes. There were no restrictions on the language and date of publication.

The population, intervention, comparison, outcome, and study design (PICOS) format was used to address the following research question: “Does foraminal enlargement influence morphologic changes of the apical foramen?” The study population was extracted human teeth submitted to root canal preparation. The intervention explored was root canal preparation with foraminal enlargement; the comparison used was root canal preparation without foraminal enlargement or instrumentation with instrument tip size similar to the foramen size. The primary outcomes evaluated were the deformation and area of the apical foramen. Secondary outcomes were touched or untouched areas by the instruments and dentinal microcrack formation. The eligible study design was *ex vivo* studies.

Search strategy and sources of information

Electronic searches were conducted in PubMed/MEDLINE, Scopus, Web of Science, SciELO, Embase and Cochrane Library databases up to April 2022. Grey literature was consulted through Google Scholar, and manual searches were carried out in the reference list of the eligible articles. The search strategy used a combination of keywords and Medical Subject Heading (MeSH) terms associated with the Boolean operators ‘AND’ and ‘OR’ as shown in Supplementary File 1.

Supplementary File 1. Search strategy used for the electronic databases

DATABASE	SEARCH STRATEGY
Medline through PubMed (http://www.ncbi.nlm.nih.gov/pubmed)	("apical enlargement"[All Fields] OR "apical preparation"[All Fields] OR "apical expansion"[All Fields] OR "apical widening"[All Fields] OR "apical debridement"[All Fields] OR "foraminal enlargement"[All Fields] OR "foraminal expansion"[All Fields] OR "foraminal widening"[All Fields] OR "foraminal debridement"[All Fields]) AND ("endodontal"[All Fields] OR "endodontic"[All Fields] OR "endodontical"[All Fields] OR "endodontically"[All Fields] OR "endodontics"[MeSH Terms] OR "endodontics"[All Fields] OR ("instrumentation"[MeSH Subheading] OR "instrumentation"[All Fields] OR "instrumentation s"[All Fields] OR "instrumentational"[All Fields] OR "instrumentations"[All Fields] OR "instrumention"[All Fields]) OR "root canal instrumentation"[All Fields] OR "root canal preparation"[All Fields] OR "root canal therapy"[All Fields] OR "root canal treatment"[All Fields]) AND ("morpholog*"[All Fields] OR "geometr*"[All Fields] OR ("alter"[All Fields] OR "alterated"[All Fields] OR "alteration"[All Fields] OR "alterations"[All Fields] OR "altered"[All Fields] OR "altering"[All Fields] OR "alters"[All Fields]) OR ("change"[All Fields] OR "changed"[All Fields] OR "changes"[All Fields] OR "changing"[All Fields] OR "changings"[All Fields]) OR "apical transportation"[All Fields] OR ("abnormalities"[MeSH Subheading] OR "abnormalities"[All Fields] OR "deformities"[All Fields] OR "congenital abnormalities"[MeSH Terms] OR ("congenital"[All Fields] AND "abnormalities"[All Fields]) OR "congenital abnormalities"[All Fields] OR "deformity"[All Fields] OR "deform"[All Fields] OR "deformabilities"[All Fields] OR "deformability"[All Fields] OR "deformable"[All Fields] OR "deformably"[All Fields] OR "deformation"[All Fields] OR "deformational"[All Fields] OR "deformations"[All Fields] OR "deformative"[All Fields] OR "deformed"[All Fields] OR "deforming"[All Fields] OR "deforms"[All Fields]) OR "apical displacement"[All Fields] OR ("crack cocaine"[MeSH Terms] OR ("crack"[All Fields] AND "cocaine"[All Fields]) OR "crack cocaine"[All Fields] OR "crack"[All Fields] OR "crack s"[All Fields] OR "cracked"[All Fields] OR "cracking"[All Fields] OR "crackings"[All Fields] OR "cracks"[All Fields]) OR "micro*"[All Fields] OR ("struct equ modeling"[Journal] OR "scan electron microsc"[Journal] OR "sem"[All Fields]))
Scopus (http://www.scopus.com/)	TITLE-ABS-KEY (("apical enlargement" OR "apical preparation" OR "apical expansion" OR "apical widening" OR "apical debridement" OR "foraminal enlargement" OR "foraminal expansion" OR "foraminal widening" OR "foraminal debridement") AND (endodontic OR instrumentation OR "root canal instrumentation" OR "root canal preparation" OR "root canal therapy" OR "root canal treatment") AND (morpholog* OR geometr* OR alteration OR change OR "apical transportation" OR deformation OR "apical displacement" OR crack OR micro* OR sem))
Cochrane (https://www.cochranelibrary.com/)	("apical enlargement" OR "apical preparation" OR "apical expansion" OR "apical widening" OR “apical debridement” OR "foraminal enlargement" OR "foraminal expansion" OR " foraminal widening" OR “foraminal debridement”) AND (endodontic OR instrumentation OR "root canal instrumentation" OR “root canal preparation” OR “root canal therapy” OR “root canal treatment”) AND (morpholog* OR geometr* OR alteration OR change OR “apical transportation” OR deformation OR “apical displacement” OR crack OR micro* OR SEM) in Title Abstract Keyword
Web of Science (https://clarivate.com/webofsciencegroup/solutions/web-of-science-core-collection/)	("apical enlargement" OR "apical preparation" OR "apical expansion" OR "apical widening" OR “apical debridement” OR "foraminal enlargement" OR "foraminal expansion" OR "foraminal widening" OR “foraminal debridement”) AND (endodontic OR instrumentation OR "root canal instrumentation" OR “root canal preparation” OR “root canal therapy” OR “root canal treatment”) AND (morpholog* OR geometr* OR alteration OR change OR “apical transportation” OR deformation OR “apical displacement” OR crack OR micro* OR SEM) (All Fields)
Embase (https://www.embase.com)	('apical enlargement' OR 'apical preparation' OR 'apical expansion' OR 'apical widening' OR 'apical debridement' OR 'foraminal enlargement' OR 'foraminal expansion' OR 'foraminal widening' OR 'foraminal debridement') AND (endodontic OR 'instrumentation'/exp OR instrumentation OR 'root canal instrumentation' OR 'root canal preparation'/exp OR 'root canal preparation' OR 'root canal therapy'/exp OR 'root canal therapy' OR 'root canal treatment') AND (morpholog* OR geometr* OR alteration OR 'change'/exp OR change OR 'apical transportation' OR 'deformation'/exp OR deformation OR 'apical displacement' OR 'crack'/exp OR crack OR micro* OR 'sem'/exp OR sem)
Scielo **(**https://scielo.org/en/)	("apical enlargement" OR "apical preparation" OR "apical expansion" OR "apical widening" OR “apical debridement” OR "foraminal enlargement" OR "foraminal expansion" OR " foraminal widening" OR “foraminal debridement”) AND (endodontic OR instrumentation OR "root canal instrumentation" OR “root canal preparation” OR “root canal therapy” OR “root canal treatment”) AND (morpholog* OR geometr* OR alteration OR change OR “apical transportation” OR deformation OR “apical displacement” OR crack OR micro* OR SEM)
Google Scholar (https://scholar.google.com/)	(“foraminal enlargement” OR “foramen enlargement” OR “foraminal debridement” OR “foraminal widening”) AND (endodontic OR "root canal therapy") AND (morpholog* OR alteration OR “apical transportation” OR deformation OR micro* OR SEM)

Study selection

Study selection was carried out independently by two reviewers (I.F.A.M. and G.C.F.), in a two-step process. Duplicates were identified and removed using Mendeley Desktop software (version 1.19.8, Elsevier Inc. New York, US). In step 1, the reviewers appraised titles and abstracts of the records retrieved from the searches. In step 2, a full-text assessment of the remaining studies was performed by the authors. Studies complied with the eligibility criteria were included in this review. Discrepancies were resolved through discussion, and when necessary, a third reviewer (A.H.R.P.) was consulted. Cohen's kappa coefficient for inter-investigator agreement during studies' selection was assessed [26].

Data extraction

One reviewer (I.F.A.M.) collected data from the included studies using a guided data extraction form in a Microsoft Excel spreadsheet. The following data were retrieved: first author's last name, year of publication, teeth used, sample size, groups and experimental protocol. Data were also collected on the analysis concerning evaluation methods and the main findings of the study. Unavailable data were classified as "not informed". Subsequently, a second author (A.C.D.V.) revised the data.

Critical appraisal of studies

The risk of bias of the selected studies was independently assessed by two reviewers (I.F.A.M. and G.O.C.), in compliance with a modified version of the Joanna Briggs Institute Critical Appraisal Checklist for Experimental Studies (JBI) [27–29]. The items included in the checklist were: clearly stated aim, justification of sample size, sample randomization, blind treatment allocation, baseline equivalence of control and treatment groups, possibility of comparison between control and treatment groups, clear description of root canal preparation, measurement method, measurement standardization, and statistical analysis. Each item was assessed on a two-point scale: 0, *not reported or reported inadequately*; 1, *reported and adequate*. Doubts and discrepancies between investigators were discussed to reach a consensus, and when necessary, a third investigator (A.H.R.P.) was consulted.

Results

Study selection

Figure 1 shows de flowchart of the selection process the studies. A total of 702 studies were found after searching the databases and through manual search in the references lists. After the first screening (Step 1), twenty-eight studies were selected and submitted to a full-text reading (Step 2). Then, 15 studies were excluded [19, 20, 30–42] with reasons being available in Figure 1. Finally, 13 were included in the qualitative analysis [15, 16, 43–51].

The assessed Cohen's kappa coefficient for inter-investigator agreement during the studies' selection was, equal to 0.917 for Pubmed, 0.922 for Scopus, 0.867 for Web of Science, 1.000 for the Cochrane Library, 0.905 for Embase, and 0.955 for Google Scholar. These values indicated an almost perfect level of agreement between reviewers during the selection of studies according to the scale of Landis and Koch [26].

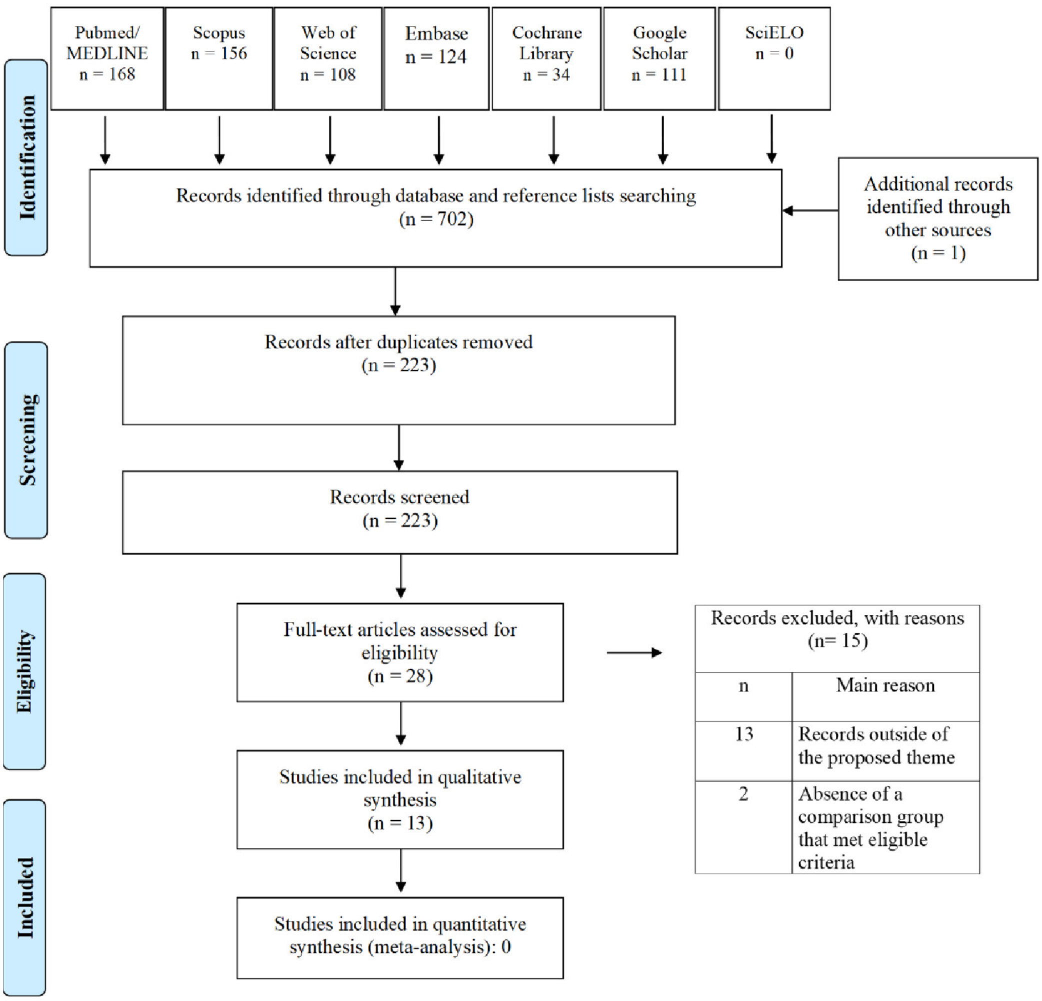

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart.

Characteristics of the included studies

Table 1 summarizes the main characteristics and results of the selected studies. All evaluations were performed in extracted human teeth, especially molars, with different root curvatures, such as straight root canal [52], mild [15, 16], and moderate to severe degree of curvature [15, 43, 45, 47–51, 53]. Two studies did not report root curvature of evaluated teeth [44, 46].

Regarding the instrumentation protocol, six studies used rotary and reciprocating systems in their experimental groups [43, 45, 47, 49–51], while other five used only rotary systems for foraminal enlargement [16, 44, 46, 52, 53], and two studies used only reciprocating systems for their experimental groups, as Reciproc Blue [15], Reciproc, WaveOne and ProDesign R [48]. Four studies also used hand-files in their groups [47, 48, 51, 52]. Additionally, mostly used sodium hypochlorite (NaOCl) in a concentration of 2% to 2.5% [15, 46, 47, 49, 50, 52] and 5.25% [45], alone or in association with ethylenediaminetetraacetic acid (EDTA) during irrigation of root canals. Most studies had groups with WL that ranged between – 1 mm and + 1 mm from the apex [15, 16, 44, 46, 47]. Additionally, one study had groups ranging between – 2 mm and + 1 mm from the apical foramen [52]. One study only reported the presence of groups with instrumentation at the major foramen [45], three studies reported groups prepared at the foramen and beyond [48–50] and other three had only groups prepared at 1 mm beyond the major foramen [43, 51, 53].

Although some studies did not report groups with different WL, instruments with different tip diameters/taper were used [43, 45, 51, 53], in which the instrument with smaller caliber served as comparison group.

Deformation and area of the apical foramen

Foraminal deformation was mostly assessed using scanning electron microscopy (SEM). Out of the 13 studies that evaluated foraminal deformation or transportation after foraminal enlargement, six presented results based on qualitative analysis of images and attribution of scores [15, 16, 44, 49, 51, 53]. Other seven studies presented results through measurement and numerical parameters that allowed a statistical comparison [43, 45–48, 50, 52].

Five studies did not observe significative differences in foraminal deformation, comparing before and after preparation images [45], among different file systems [43] or different WL [15, 47, 48]. For the other eight studies, when foraminal deformation after instrumentation was noticed, it was predominantly associated to instrumentation at least 1 mm beyond the apex [16, 44, 46, 51, 53], although instrumentation at the foramen already led to foraminal deformation in three studies [49, 50, 52].

In addition to the WL limit, other factors were also associated with deformation, such as the final diameter of the foraminal preparation [16, 44, 46, 47, 49, 50, 52, 53], kinematics of the instruments [43, 45, 47, 49–51] and alloy characteristics [48–51, 53].

Out of the studies that described foraminal shape alteration after foraminal instrumentation, one observed a tendency for its shape gradually change from circular to oval as the WL increased [50]. However, another study noted that foramen shape remained circular after foraminal enlargement in most specimens [43]. Furthermore, one study observed a more regular shape of the foramen after foraminal enlargement [46].

Eight studies also showed that foraminal enlargement led to a significant increase in the foraminal area [43–48, 50, 53].

Secondary outcomes

Two studies evaluated the untouched cementum walls before and after instrumentation using a stereomicroscope [47] or SEM [16] and showed that the percentage of all touched cementum walls were similar when instrumentation was performed at the foramen or 1mm beyond.

The occurrence of dentinal microcracks were evaluated in two studies using a stereomicroscope [52], and micro-computed tomography (micro-CT) [15]. The findings were controversial, which it was not sufficient to assert a conclusion.

Critical appraisal of included studies

Table 2 and Figure 2 summarize the results of the risk of bias assessment by using the JBI tool. All the included articles showed a clearly stated aim, baseline equivalence of control and treatment groups, clear root canal preparation protocol, measurement standardization, reliable measurement method, and adequate statistical approach. A low risk of bias was observed in the possibility of comparison between groups, in which only one study did not report this item appropriately [45]. However, a high risk of bias was noticed for some domains, including justification of sample size, sample randomization and blind treatment allocation.

Table 1. Characteristics and main results of included *ex vivo* studies

Author / Year	Teeth used	n	Groups	Estimated final FD according to MAF nominal diameter (mm)*	Outcomes/Analysis	Main results
Bezerra ***et al.*** **2021** [43]	Mandibular and maxillary human molars (15º-35º) with FD ≤ 0.20 mm	30	G1: PDL (#25/.01, #25/.06 and #35/.05), WL = +1 mm, n.i.; G2: PDS (#25/.01), PDR (#25/.06, #35/.05), WL = +1 mm, n.i.; G3: TFA (#20/.04, #25/.06 and #35/.04), WL = +1 mm, n.i.; G4: ProGlider (#16/.02) WOG (#25/.07, 35/.06), Wl = +1 mm, n.i.	G1: 0.40 G2: 0.40 G3: 0.39 G4: 0.41	Foraminal area and foramen shape using a digital microscope	Foraminal enlargement significantly increased foraminal area in comparison with the shaping file #25, and foramen shape was mostly circular
Souza ***et al.*** **2021** [44]	Human mandibular premolars	10	G1: Largo #2, Hero (#20/.06), GG drills (#5, #4, #3, #2), Mtwo (#40/.04), WL = +1 mm, 2% CHX gel, 0.9% saline solution, 17% EDTA; G2: Largo #2, Hero (#20/.06), GG (#5, #4, #3, #2), Mtwo (#40/.04), WL = -1 mm, 2% CHX gel, 0.9% saline solution, 17% EDTA, 0.9%.	G1: 0.44 G2: n/a	Foraminal area and foraminal transportation using SEM.	Foraminal enlargement increased foraminal area and increased foraminal transportation
Daou ***et al.*** **2020** [45]	MB roots of humans mandibular and maxillary molars (20º-40º, r = 2-6 mm) with FD = 0.18-0.23 mm	20	G1: Reciproc Blue R25 (#25/.08); WL = 0.0, 5.25% NaOCl, 17% EDTA, and DW; G2: XP-endo Shaper (#30/.04); WL = 0.0, 5.25% NaOCl, 17% EDTA, and DW.	G1: 0.25 G2: 0.30	Foraminal area, circularity and ratio of Feret diameters using SEM	Foraminal instrumentation increased foraminal area, but did not promote foraminal deformation
Vieira ***et al.*** **2020** [15]	Human mandibular incisors with straight roots (0º-10º); Mesial roots of human mandibular first molars (10º-20º)	n = 30 per type of tooth; n = 15 per analysis.	SEM: G1: incisor, Reciproc Blue R25 (#25/.08), WL = 0.0, 2.5% NaOCl; G2: molar, R25, WL = 0.0, 2.5% NaOCl; G3: incisor, R25, WL = +1 mm, 2.5% NaOCl; G4: molar, R25, WL = +1 mm, 2.5% NaOCl. µ-CT: G5: incisor, R25, WL = -1 mm, 2.5% NaOCl; G6: molar, R25, WL = -1 mm, 2.5% NaOCl; G7: incisor, R25, WL =	G1, G2, G7, G8 (WL = 0.0): 0.25 G3, G4, G9, G10 (WL = +1 mm): 0.33	Foraminal deformation using SEM and dentinal microcracks using µ-CT	Foraminal enlargement resulted in foraminal deformation without significative difference when WL = 0 or +1 mm; foraminal enlargement did not influence dentinal microcracks

			0.0; G8: molar, R25, WL = 0.0, 2.5% NaOCl; G9: incisor, R25, WL = +1 mm, 2.5% NaOCl; G10: molar, R25, WL = +1 mm, 2.5% NaOCl			
Marin 2019 [46]	Single-rooted human teeth; FD ≤ 0.40 mm	12	G1: PDL (#25/.06 and #40/.05), WL = -1 mm, 2.5% NaOCl and 17% EDTA G2: PDL (#25/.06, #40/.05 and Glide Path file #45/.01), WL = 0.0, 2.5% NaOCl and 17% EDTA; G3: PDL (#25/.06, #40/.05 and Glide Path file #45/.01), WL = +1 mm, 2.5% NaOCl and 17% EDTA; G4: PDL (#25/.06, #40/.05 and Glide Path file #50/.01), WL = 0.0, 2.5% NaOCl and 17% EDTA; G5: PDL (#25/.06, #40/.05 and Glide Path file #50/.01), WL = +1 mm, 2.5% NaOCl and 17% EDTA	G1: max 0.40 G2: 0.45 G3: 0.46 G4: 0.50 G5: 0.51	Foraminal area and foraminal transportation using SEM	Foraminal enlargement increased foramen area compared to instrumentation 1 mm short of the foramen (control); it increased foraminal transportation compared to control
Schmidt 2019 [47]	MB and ML canals of human mandibular molars (curvature <30º)	10	G1: R25 (#25/.08) WL = -1 mm, K #10 at foramen, 2.5% NaOCl; G2: R25 WL = -1 mm, FF (#20, #25 or #30) at foramen, 2.5% NaOCl; G3: PDS (#25/.01, #30/.10, #25/.06, #25/.08), WL = 0.0, 2.5% NaOCl; G4: R25, WL = 0.0, 2.5% NaOCl; G5: PDS (#25/.01, #30/.10, #25/.06, #25/.08), WL = +1 mm, 2.5% NaOCl; G6: R25, WL = +1 mm, 2.5% NaOCl	G2: 0.20, 0.25 or 0.30 G3: 0.25 G4: 0.25 G5: 0.33 G6: 0.33	Foraminal area, perimeter, and untouched cementum wall using a stereomicroscope, and apical transportation using μ-CT	Foraminal enlargement increased foraminal area and deviation; instrumentation 1 mm beyond the foramen did not influence untouched cementum walls compared to instrumentation 1 mm short of apical foramen
Frota *et al.* 2018 [48]	Mesial roots of human mandibular molars (10º-25º) with FD ≤ 0.20mm	15	G1: GG drills (#4, #3, #2), FF (#50-#25), WL = 0.0, DW; G2: GG drills (#4, #3, #2), FF (#50-#25), WL= +1 mm, DW; G3: R25 (#25/08), WL = 0.0, DW; G4: R25 (#25/08), WL = +1 mm, DW; G5: WO Primary (#25/08), WL = 0.0, DW; G6: WO Primary (#25/08), WL = +1 mm, DW;G7: PDR (#25/06), WL = 0.0, DW; G8: PDR (#25/06), WL = +1mm, DW.	G1: 0.25 G2: 0.27 G3: 0.25 G4: 0.33 G5: 0.25 G6: 0.33 G7: 0.25 G8: 0.31	Foraminal area and foraminal deformation using a stereomicroscope	Foraminal enlargement had higher percentage of foraminal area increase and non-statistical foraminal deformation compared to controls, although a trend for greater deformation with WL beyond the foramen

						and M-Wire alloy was observed
Silva Santos *et al.* 2018 [49]	MB roots of mandibular and maxillary human molars (30º-65º, r = 2-6mm)	30	G1: PTU (SX, S1, F1, F2), WL = 0.0, 2.5% NaOCl; G2: PTU (SX, S1, F1, F2), WL = +1 mm, 2.5% NaOCl; G3: PathFile (#1, #2, #3) and WO Primary file (#25/.08), WL = 0.0, 2.5% NaOCl; G4: PathFile (#1, #2, #3) and WO Primary file (#25/.08), WL = +1 mm, 2.5% NaOCl.	G1: 0.25 G2: 0.33 G3: 0.25 G4: 0.33	Foraminal deformation using SEM	Foraminal enlargement increased foraminal deformation compared to baseline images
Yammine *et al.* 2017 [50]	MB or ML canals of mandibular and maxillary human molars (20º-40º) with FA = 15-25 mm^2	15	G1: non instrumented; G2: ProGlider (#16/.02), ProTaper Next (X1 #17/.04, X2 #25/.06), WL = 0.0; G3: ProGlider (#16/.02), PTN (X2 #25/.06), WL = +0.5 mm; G4: ProGlider (#16/.02), PTN (X2 #25/.06), WL = +1 mm; G5: ProGlider (#16/.02), PTN (X2 #25/.06), WL = +1.5 mm; G6: K-file (#10, #15), BT1 (#10/.06), BT2 (#35/.00), BT3 (#35/.04), WL = 0.0; G7: K-file (#10, #15), BT1 (#10/.06), BT3 (#35/.04), WL = +0.5 mm; G8: K-file (#10, #15), BT1 (#10/.06), BT3 (#35/.04), WL = +1 mm; G9: K-file (#10, #15), BT1 (#10/.06), BT3 (#35/.04), WL = +1.5 mm; G10: ProGlider (#16/.02), WOG Primary (#25/.07), WL = 0.0; G11: ProGlider (#16/.02), WOG Primary (#25/.07), WL = +0.5 mm; G12: ProGlider (#16/.02), WOG Primary (#25/.07), WL = +1 mm; G13: ProGlider (#16/.02), WOG Primary (#25/.07), WL = +1.5 mm. For all groups, irrigation was performed with 2.5% NaOCl and 17% EDTA	G1: n/a G2: 0.25; G3: 0.28; G4: 0.31; G5: 0.34; G6: 0.35; G7: 0.37; G8: 0.39; G9: 0.41; G10: 0.25; G11: ≅0.28; G12: 0.32; G13: ≅0.35.	Foraminal area and shape using stereomicroscopy	Foraminal enlargement increased foramen area, especially in BTR groups, in addition it tends to gradually change from circular to oval as the WL increases

Silva *et al.* 2016 [16]	Palatal roots of human molars (curvature ≤ 5°)	15	For all groups, instrumentation in cervical and middle thirds was performed with K3 files (#25/.10, #25/.08) and apical third with IAF + 3 with a .06 taper. G1: WL= -1 mm, 2% CHX, saline solution and 17% EDTA; G2: WL = 0.0, 2% CHX, saline solution and 17% EDTA; G3: WL = +1 mm, 2% CHX, saline solution and 17% EDTA	n/a	Foraminal area, transportation using SEM images	Foraminal enlargement increased cementum removal, and instrumentation + 1mm beyond the foramen led to greater foraminal deviation
Silva *et al.* 2014 [51]	DB roots of human maxillary molars (10º-20º) with FD ≅ 0.10mm	10	G1: GG drills (#4, #3, #2), FF (#50-#25), WL = +1 mm, 0.9% saline solution; G2: Mtwo (#10/.04, #15/.05, #20/.06, #25/.06), WL= +1 mm, 0.9% saline solution; G3: R R25, WL = +1 mm, 0.9% saline solution	G1: 0.27 G2: 0.31 G3: 0.33	Foraminal transportation using SEM	Foraminal enlargement with hand files showed the greatest foraminal deformation, while Reciproc system showed the lowest deformation among the groups
Liu *et al.* 2013 [52]	Human mandibular incisors with straight roots	20	G1: GG drills (#2 and #1), K3 rotary files (#35/.04 up to #25/.06), WL = - 2 mm; G2: GG drills (#2 and #1), K3 rotary files (#35/.04 - #25/.06), WL = -1 mm; G3: GG drills (#2 and #1), K3 rotary files (#35/.04 - #25/.06), WL = 0.0; G4: GG drills (#2 and #1), K3 rotary files (#35/.04 - #25/.06), WL = +1 mm; G5: GG drills (#2 and #1), ProTaper (SX up to F3), WL= -2 mm; G6: GG drills (#2 and #1), ProTaper (SX up to F3), WL = -1 mm; G7: GG drills (#2 and #1), ProTaper (SX up to F3), WL = 0.0 mm; G8: GG drills (#2 and #1), ProTaper (SX up to F3), WL = +1 mm; G9: GG drills (#2 and #1), Flex HF (20-35, SB: 40-50), WL = -2 mm; G10: GG drills (#2 and #1), Flex HF (20-35, SB: 40-50), WL = -1 mm; G11: GG drills (#2 and #1), Flex HF (20-35, SB: 40-50), WL = 0.0 mm;	G1: n/a G2: n/a G3: 0.35 G4: 0.39 G5: n/a G6: n/a G7: 0.30 G8: 0.39 G9: n/a G10: n/a G11: 0.35 G12: 0.40	Dentinal detachments and apical cracks using stereomicroscope	Foraminal enlargement increased dentinal detachments and cracks than controls, especially when using mechanized files

			G12: GG drills (#2 and #1), Flex HF (20-35, SB: 40-50), WL = +1 mm. For all groups, irrigation was performed with 2% NaOCl			
Lima *et al.* 2012 [53]	MB and DB roots of human maxillary molars (10º-15º)	10	G1: Largo (#4), GG drills (#5, #4, #3, #2), ProDesign (#20/.03, #15/.05, #22/.04, #25/.04, #20/.06, #20/.07), WL = +1 mm, 2% CHX gel and saline solution; G2: Mtwo (#10/.04, #15/.05, #20/0, #25/.06, #30/.05, #35/.04, #40/.04, #25/.07), WL = +1 mm, 2% CHX gel and saline solution	G1: 0.29 G2: 0.44	Foraminal area using SEM images	Foraminal enlargement with larger apical file (G2) significantly increased the foramen area compared to G1, whereas both groups showed foraminal transportation

The symbol < indicates 'less than', ≤ indicates 'less than or equal to', ≅ indicates 'approximately equal to', mm: millimeters.
CHX: chlorhexidine, µ-CT: micro-computed tomography, DB: distobuccal, DW: distilled water, EDTA: ethylenediaminetetraacetic acid, FA: foraminal area, FD: foraminal diameter, FF: Flexofile, G: group, GG: Gates-Glidden, HF: hand files, IAF: initial apical file (first file that binds the foramen), MAF: master apical file (larger file used to enlarge apical region), MB: mesiobuccal, ML: mesiolingual, n/a: not applicable, NaOCl: sodium hypochlorite, n.i.: not informed, NiTi: nickel-titanium, PDL: ProDesign Logic, PDS: ProDesign S, PDR: ProDesign R, PFV: ProFile Vortex, PTU: ProTaper Universal, r: radius of curvature, R: Reciproc, SB: step-back, SEM: scanning electron microscopy, TFA: Twisted File Adaptive, WL: working length, WO: WaveOne, WOG: WaveOne Gold.
*This column refers to the final FD, considering the determined WL and file tip and taper described by the manufacturers.

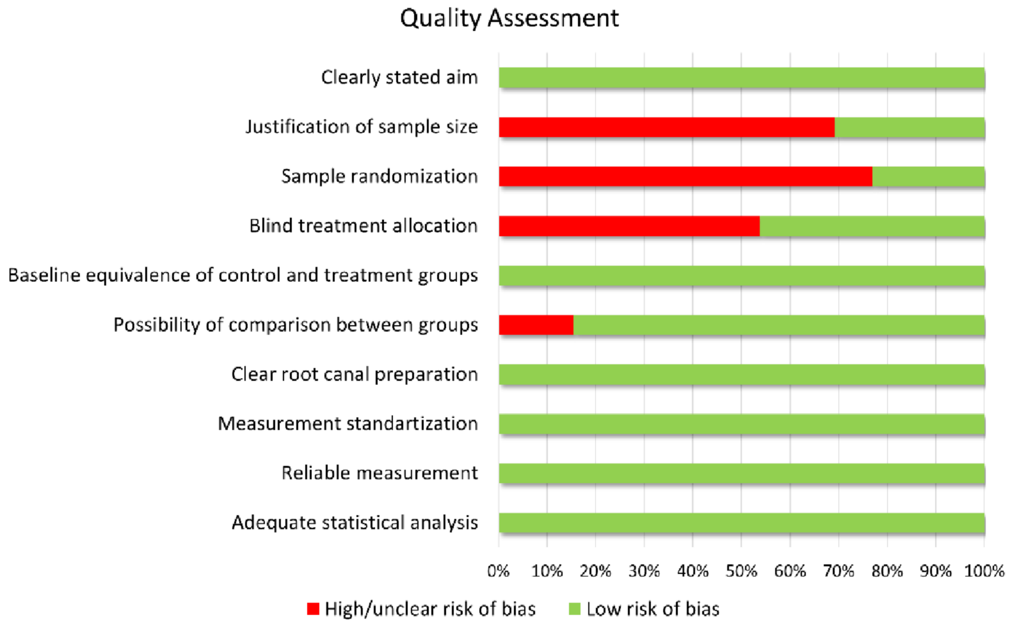

Figure 2 Assessment of the risk of bias in the included studies according to the percentage of the scores attributed to each evaluated study.

Table 2. Critical appraisal of included studies

Quality criteria	Was the aim of the study clearly stated?	Was the sample size justified?	Was the assignment to treatment groups truly random?	Were those assessing the outcomes blind to the treatment allocation?	Were control and treatment groups comparable at entry?	Were groups treated identically other than for the named interventions?	Was root canal preparation clearly described?	Were outcomes measured in the same way for all groups?	Were outcomes measured in a reliable way?	Was appropriate statistical analysis used?	**Total score**
Bezerra *et al.* 2021 [43]	1	1	0	1	1	1	1	1	1	1	9
Souza *et al.* 2021 [44]	1	1	1	1	1	1	1	1	1	1	10
Daou *et al.* 2020 [45]	1	0	1	1	1	0	1	1	1	1	8
Vieira *et al.* 2020 [15]	1	0	0	0	1	1	1	1	1	1	7
Marin 2019 [46]	1	0	0	0	1	1	1	1	1	1	7
Schmidt 2019 [47]	1	0	0	0	1	1	1	1	1	1	7
Frota *et al.* 2018 [48]	1	1	0	0	1	1	1	1	1	1	8
Silva Santos *et al.* 2018 [49]	1	1	0	1	1	1	1	1	1	1	9
Yammine *et al.* 2017 [50]	1	0	0	0	1	1	1	1	1	1	8
Silva *et al.* 2016 [16]	1	0	0	1	1	1	1	1	1	1	8
Silva *et al.* 2014 [51]	1	0	1	1	1	0	1	1	1	1	8
Liu *et al.* 2013 [52]	1	0	0	0	1	1	1	1	1	1	7
Lima *et al.* 2012 [53]	1	0	0	0	1	1	1	1	1	1	7

0, not reported or reported but inadequate; 1, reported and adequate

Synthesis of results

Meta-analysis was not performed due to wide variations in methods for assessment, anatomical variation of samples, NiTi systems and protocols used for root canal preparation among the included *ex vivo* studies. In addition, a lack of available data was observed for some evaluated outcomes.

Discussion

This systematic review primarily investigated the morphological changes of the major apical foramen after foraminal enlargement with data from 13 *ex vivo* studies. Most studies showed increased foraminal deformation and area after foraminal enlargement.

Besides the different WL considered for foraminal enlargement in the literature, such as instrumentation at the major foramen [45] or beyond [43, 44, 53], the size of the endodontic instrument used during instrumentation is also an important consideration. In this procedure, the endodontic instrument tip and taper must guarantee the preparation of the cemental canal [16, 46, 53]. Clinically, a common practice is to firstly estimate the apical foraminal size, known as the initial apical file (IAF), and subsequently, choose the instrument that will be used for foraminal enlargement [16]. The chosen IAF is normally smaller than the actual size of the foramen [23, 54]. From that, one possibility to determine how much to enlarge, in terms of instrument diameter, is increasing apical enlargement to three ISO diameters larger than IAF [16].

Regarding deformation of the apical foramen, most studies used SEM images for evaluation, in which a magnification ranging from ×50 to ×200 was reported [15, 16, 44–46, 49, 53]. Photomicrographs were analyzed with the aid of software to perform measurements and comparisons after different instrumentation moments. SEM allows increasing measurement accuracy and is a viable method when analyzing a large sample [45], meanwhile it requires a device to standardize the acquisition of the consecutive images [44, 45, 49]. Most studies concluded that instrumentation at the major foramen or beyond the apex promoted foraminal deformations [16, 44, 46, 47, 49–52]. Other two showed a tendency of foraminal deformation associated to instrumentation 1 mm beyond the apex, without statistical significance [43, 48]. The occurrence of foraminal deformation or transportation may negatively impact in the quality of obturation [8, 55], enhancing the possibility for overflow of filling materials [8], although only two included studies demonstrated that sealing ability is not affected by over-instrumentation [16, 44].

Absence of significant foraminal deformation were shown when mechanized instruments with smaller tip diameters (.25 mm or .30 mm) were used at the level of the apical foramen, in comparison to pre-instrumentation images [45], or to instrumentation short of the foramen plus manual clearing at the foramen [47]. However, instruments with #25 tip size showed to be able to cause apical transportation when instrumentation reached foramen [47, 49, 50] or an over instrumentation was promoted [49, 53]. In cases of instrumentation 1 mm beyond the apex or more, the final enlargement diameter plays an important role in determining apical deformations. It was found that apical diameters above 0.29 mm were already capable of causing transport or foraminal deformation [44, 46, 49, 53]. Discrepancies in the findings may be due to methodological heterogeneity amongst studies, such as the use of instruments with different geometric characteristics and different methods of analysis.

One factor that might have effect on the deformation of the apical foramen is the type of alloy of the endodontic instrument. For instance, Frota *et al*. [48] observed that foraminal preparation with a #25.06 instrument with shape memory effect caused less foraminal deformation than M-Wire #25.08 instruments, regardless of the WL. The authors attribute this result not only to the difference in instrument taper, but also to the greater flexibility of the NiTi-based alloy from which the instrument is made. In fact, controlled memory NiTi alloys demonstrate superior flexibility than superelastic alloys [56, 57]. However, due to geometry differences among instruments used by the authors, it is not possible to confirm that hypothesis. Another study [50] that compared foraminal deformation with the use of three mechanized systems (ProTaper Next, BT Race and WaveOne Gold), also observed foraminal deformation after over-instrumentation, but thermically treated WaveOne Gold instruments obtained better results in the maintenance of foraminal anatomy, despite the geometric design differences and higher taper in relation to the ProTaper Next (PTN) instruments. More studies are necessary to investigate if controlled memory alloys are the major factors promoting less foraminal deformation than stainless steel or superelastic alloys, or if these differences are due to other reasons, such as the off-centered cross-section of PTN files.

In shape analysis, few data with controversial results were found. One study demonstrated a change from circular to oval after foraminal enlargement [50], while another found a circular shape in originally oval foramens after foraminal enlargement with #40/.01 or #50/.01 glide-path files [46]. On the contrary, two reported few cases of irregular shapes after over-instrumentation [43, 53]. Differences in root canal curvature amongst the samples and the use glide-path files for foraminal enlargement may influence these controversial results. The use of instruments with reduced taper may provide greater flexibility than larger taper files, in which may reduce foraminal deformation [46].

Although it would be expected to see an increase in the foraminal area or in the prepared cemental walls when using the same instrument at the level of the foramen or 1 mm beyond [48], some studies did not observe a significant difference in these parameters [16, 47].

The eight studies, of the 13 included, that evaluated foraminal area after foraminal enlargement, observed that this procedure increased foraminal area, demonstrating that foraminal enlargement really happened within the parameter used by the authors [43–48, 50, 53].

Only a few studies evaluated the occurrence of dentinal microcracks showing controversial results. One study [15] showed no influence of foraminal enlargement on the presence of dentinal microcracks, whereas another found that foraminal enlargement increased the occurrence of this outcome [52]. These different results may be related to the different method of analysis between the articles, stereomicroscope [52] or micro-computed tomography (micro-CT) [15], and the different instrumentation protocol adopted in each study. According to Vieira *et al*. [15], micro-CT is considered the gold-standard and nondestructive method to evaluate microcracks in tooth root surface.

Regarding critical appraisal of the eligible studies, a modified version of the JBI critical appraisal tool was chosen for assessing methodological and reporting quality of the studies. Methodological limitations regarding the report of sample size justification, sample randomization and blinding evaluation were observed in most included studies. Then, well-designed evaluations with standardized methodologies, considering anatomical variations, are necessary to provide stronger evidence. Conversely, a low risk of bias and adequate reporting were present for the majority of the items, which may lead to overall high quality evidence.

Significant methodological heterogeneity is a common practice in laboratory studies [58]. An increased variability in the instrumentation protocol, tip diameter and taper of the instruments, determination of WL, and root canal curvature were observed in this systematic review. Therefore, it was difficult to perform cross-study comparisons due to the lack of uniformity in methodologies. Additionally, only *ex vivo* models using extracted human teeth were selected, which has to be considered when interpreting the findings and making assumptions to the clinical setting. Thus, further clinical outcome assessment using precise methods for analyses, such as micro-CT, are encouraged.

Conclusion

It is noted that foraminal enlargement during root canal preparation seems to increase deformation and area of the major apical foramen, especially when WL is at least one millimeter beyond the foramen. However, it was not possible to conclude if there is a conservative, but effective, protocol for foraminal enlargement due to great methodological heterogeneity of studies. Well-designed evaluations with standardized methodologies are necessary to provide stronger evidence.

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5 CONSIDERAÇÕES FINAIS

A instrumentação da região foraminal, resultando em um alargamento intencional dessa região, tem sido defendida por alguns pesquisadores, almejando-se maiores limpeza e descontaminação. Este procedimento, mesmo amparado por diversos trabalhos encontrados na literatura, pode ainda apresentar certa resistência por profissionais preocupados com as consequências da ampliação e deformação do forame apical, como um possível maior risco de dor pós-operatória e de interferências na obturação dos canais radiculares.

Estudos incluídos nesta revisão, que avaliaram a deformação foraminal a partir de parâmetros numéricos, o fizeram ou pela razão/diferença entre maior e menor diâmetro do forame, ou pelo traçado da diferença entre seus centros de gravidade antes e após a instrumentação. Análises qualitativas e dependentes da interpretação dos autores também foram observadas.

A partir dos resultados apresentados, pode-se observar uma tendência à deformação foraminal com a sobreinstrumentação a partir de um milímetro além do forame maior, embora alguns estudos já demonstrem tal desfecho com o preparo mecânico ocorrendo ao nível do forame.

Instrumentos de níquel-titânio fabricados a partir de ligas com efeito memória de forma parecem apresentar melhores resultados em relação à deformação foraminal quando comparados aos instrumentos de níquel-titânio superelásticos ou de aço inoxidável. Mais estudos relacionados ao tema, entretanto, são necessários.

Devido à grande heterogeneidade metodológica dos trabalhos incluídos nesta revisão, não foi possível estabelecer um protocolo conservador, porém efetivo, para a realização de uma ampliação foraminal segura. Outros estudos bem delineados, com metodologias padronizadas são necessários para fornecer evidências mais robustas.

Recomendações para pesquisas futuras também compreendem estudos que analisem mais além as possíveis consequências clínicas da deformação foraminal.

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