

PONTIFÍCIA UNIVERSIDADE CATÓLICA DO PARANÁ ESCOLA DE CIÊNCIAS DA VIDA PROGRAMA DE PÓS-GRADUAÇÃO EM ODONTOLOGIA ÁREA DE CONCENTRAÇÃO CLÍNICA ODONTOLÓGICA INTEGRADA ÊNFASE EM ENDODONTIA

## ANDRÉ VINÍCIUS KALED SEGATO

# PRECISÃO DE UM NOVO SOFTWARE NA DETERMINAÇÃO DO COMPRIMENTO DE TRABALHO DO CANAL RADICULAR POR MEIO DA TOMOGRAFIA COMPUTADORIZADA DE FEIXE CÔNICO. ESTUDO EX VIVO

Curitiba 2018

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Dissertação apresentada ao Programa de Pós-Graduação em Odontologia da Pontifícia Universidade Católica do Paraná, como parte dos requisitos para obtenção do título de Mestre em Odontologia, Área de Concentração em Clínica Odontológica Integrada com ênfase em Endodontia.

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TERMO DE APROVAÇÃO

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## ARTIGO EM PORTUGUÊS

## Página título

Precisão de um novo software na determinação do comprimento de trabalho do canal radicular por meio da tomografia computadorizada de feixe cônico. Estudo ex vivo

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## Resumo

Introdução: O presente estudo investigou a precisão do software 3D Endo (Dentsply Sirona, Salzburg, Austria) na determinação do comprimento de trabalho do canal radicular, a partir de imagens de dentes extraídos obtidas pela tomografia computadorizada de feixe cônico (TCFC) e comparou com a precisão de um software convencional e um localizador foraminal eletrônico (LFE). Método: imagens de TCFC de 30 pré-molares foram obtidas. Usando o software OnDemand 3D (Cybermed, Seoul, Korea) foi obtida uma medida a partir da referência coronal até o forame apical (FA) e registrada como comprimento convencional (CC). Então, usando o software 3D Endo (Dentsply Sirona) o comprimento sugerido (3D-CS) e o comprimento ajustado pelo operador (3D-CAO) foram obtidos. Os dentes foram acessados e o comprimento real verificado. Finalmente, os dentes foram embebidos em alginato para se obter o comprimento eletrônico (CE) usando o LFE Root ZX II (J Morita, Tokyo, Japão). A média dos valores absolutos e a distribuição da porcentagem dos diferentes métodos foram comparados com as medidas do comprimento real. Resultados: não houve diferença entre a média das medidas (análise de variância p> .05). Todas as medidas obtidas pela TCFC apresentaram alta confiabilidade (fórmula de Dahlberg). As medidas entre a faixa de  $\pm$  0.5mm do FA foram de 86,6% para o 3D-CS, 80% para 3D-CAO e LA e 73,3% para o CC. O CE apresentou significativamente menos medidas subestimadas (p< .05). O 3D-CAO e o 3D-CS apresentaram significativamente menos medidas além do FA (p< .05). Conclusão: determinar o comprimento de trabalho usando o 3D Endo foi confiável e similar ao software OnDemand 3D. Entretanto, o uso combinado da TCFC com o LFE é fundamental para se obter maior precisão em localizar o FA.

**Palavras-chave:** 3D endo, tomografia computadorizada de feixe cônico, localizador foraminal eletrônico, endodontia, comprimento de trabalho

## Introdução

A determinação de um limite apical apropriado é de extrema importância para o sucesso do tratamento endodôntico (1, 2). Sub ou superestimar o comprimento de trabalho (CT) pode acarretar, respectivamente, em insuficiente desinfecção do sistema de canais radiculares ou gerar danos aos tecidos periapicais (1, 2). O forame apical (FA) é onde está localizada a saída do canal radicular e a constrição apical (CA) é o menor diâmetro do canal radicular. A CA está localizada de 0.5 a 1 mm aquém do FA e é considerada o ponto ideal para a modelagem e obturação do sistema de canais radiculares (2).

Atualmente, as radiografias periapicais e os localizadores foraminais eletrônicos (LFE) são os métodos mais utilizados para determinar o comprimento de trabalho. Os LFE são mais precisos e confiáveis do que as radiografias (3, 4), mas a sua precisão pode ser afetada por complexidades anatômicas, ausência de patência do canal radicular ou pela presença de restaurações metálicas (3-6). Por outro lado, limitações da radiografia convencional são atribuídas à sua natureza bidimensional, que impede a determinação precisa do CT em casos de curvaturas no sentido vestíbulo-lingual (VL), dificulta a detecção do forame lateral, além de promover distorções e sobreposição de estruturas anatômicas (4, 7).

A tomografia computadorizada de feixe cônico (TCFC) é um método radiológico contemporâneo que fornece imagens tridimensionais de estruturas anatômicas facilitando o diagnóstico e propiciando maior previsibilidade ao tratamento endodôntico (8-12). Um exame por TCFC pré-existente pode ser utilizado para a mensuração do CT pré-operatório (13-15). Entretanto, não há um consenso na literatura a respeito da precisão da TCFC na determinação do CT quando comparada com métodos tradicionais, como os LFE e as radiografias periapicais (7, 13-19).

A discrepância entre vários estudos pode estar relacionada ao método usado para se obter o comprimento de trabalho através das imagens, que dependem das ferramentas de medição disponíveis nos softwares para TCFC. A maioria desses softwares usa uma régua como ferramenta de medição que pode ser usada para mensurar qualquer distância, mas usualmente utilizada em um

plano bidimensional. Em outras palavras, o operador precisa procurar a melhor visão sagital que representa o comprimento do canal para então desenhar uma linha da referência coronária até o FA (16-18, 20). Para canais curvos, foi sugerido o uso de uma linha segmentada que permite realizar a trajetória curva dos canais em diferentes planos, (14, 15, 19, 21) ou desenhar uma linha horizontal no ponto de referência coronário e conectar até o FA em outro plano (20). Além disso, alguns estudos usam a média das medidas obtidas entre os planos mésio-distal e vestíbulo-lingual como mensuração do CT (14, 21). Essa diferença entre metodologias pode afetar negativamente a reprodutibilidade dos estudos e dificultar a comparação dos resultados entre eles (7, 16, 20).

Recentemente o software 3D Endo<sup>™</sup> (Dentsply/Sirona, Wels bei Salzburg, Austria) foi desenvolvido especificamente para o planejamento do tratamento endodôntico, fornecendo maior previsibilidade (22). Ele apresenta uma interface intuitiva, na qual o clínico pode seguir as etapas de identificação e mensuração dos canais, bem como realizar o planejamento virtual da cavidade de acesso, identificar o limite apical e selecionar os instrumentos endodônticos para os procedimentos de modelagem do canal. Um estudo recente reportou que esse software permite uma melhor visualização tridimensional das complexidades anatômicas como curvaturas e confluência dos canais (23). Uma característica inovadora desse software é a detecção semiautomática da trajetória do canal radicular: após identificar o orifício de entrada do canal e o FA, uma linha automática conecta-os, permitindo seguir a trajetória do canal em três dimensões. Usando essa trajetória como referência, um instrumento endodôntico virtual é usado para estimar o CT. O CT pode ser obtido através de duas maneiras, sugestão automática do software ou pelo ajuste manual do clínico. A detecção semiautomática da trajetória do canal radicular minimiza erros subjetivos relacionados a habilidade do operador (21, 23, 24).

Embora esse software seja usado clinicamente, uma investigação laboratorial é necessária para validar essas estimativas do CT comparadas com o padrão ouro, obtida através do comprimento real de dentes extraídos (13). Além disso, é importante verificar se as ferramentas semiautomáticas oferecem alguma vantagem em relação ao uso de um software convencional para análise de

imagens obtidas através da TCFC. Portanto, o objetivo desse estudo foi investigar a precisão do software 3D Endo<sup>™</sup> na determinação do comprimento de trabalho do canal radicular e comparar com um software convencional para TCFC e um localizador foraminal eletrônico.

## Materiais e Método

Esse estudo foi aprovado pelo comitê de ética e pesquisa local (protocolo 2.348.485). Noventa pré-molares inferiores extraídos de humanos, unirradiculares e armazenados em solução de timol a 0,1% e uma mandíbula seca foram obtidos na Escola de Ciências da Vida da Pontifícia Universidade Católica do Paraná (Curitiba, Brasil). Os dentes foram avaliados através de um microscópio operatório sob magnificação de 10x (DF Vasconcellos, Londrina, Brasil) para excluir raízes com: ápice incompleto, fraturas, presença de forames laterais ou que apresentavam reabsorção/cárie radicular (6). Então, os dentes foram escaneados por meio da TCFC, Scanora 3D (Soredex Tuusula, Finlândia) com 120 kVp, 12.5 mA, FOV of 75 x 100 mm, e voxel 0.2mm para avaliar e padronizar parâmetros anatômicos. Finalmente, a amostra foi constituída por 30 dentes seguindo a configuração tipo I de Vertucci e sem a presença de mineralização, material obturador ou acesso prévio ao canal radicular. Os dentes selecionados foram lavados em solução fisiológica e a cúspide vestibular foi regularizada com disco de carborundum para se obter um ponto de referência coronal reprodutível.

## Obtenção das medidas pela TCFC

Os dentes foram numerados e 4 dentes por vez foram selecionados aleatoriamente sendo 2 dentes colocados em alvéolos de pré-molares inferiores do lado direito e 2 do lado esquerdo de uma mandíbula seca (16). A mandíbula foi fixada na base de um recipiente plástico contendo água em seu interior para simular os tecidos moles (25) e o escaneamento foi realizado através da TCFC (Scanora 3D, Soredex Tuusula, Finland) com 90 kV, 13 mA, FOV de 60 x 60 mm, e voxel size de 0.133mm<sup>3</sup>.

A análise de todas as imagens foi realizada por um endodontista experiente, em uma sala escura, através de um computador com as seguintes configurações: Microsoft Windows XP Professional (Microsoft Corp, Redmond, WA, EUA), tela de 22.5" e uma resolução de 1920x1200 pixels.

As imagens foram primeiramente analisadas usando o software OnDemand 3D (Cybermed, Seoul, Coreia). O dente selecionado foi posicionado verticalmente e ligeiramente rotacionado para se obter um único corte sagital e coronal que melhor representasse todo o comprimento do canal no sentido mésio-distal (MD) e vestíbulo-lingual (VL) respectivamente (19). Uma linha de medida foi traçada do ponto de referência oclusal até o FA, de maneira centralizada e seguindo a anatomia interna (Fig.1). A média das medidas obtidas no sentido MD e VL foram registradas como comprimento convencional (CC).

Após duas semanas, as mesmas imagens foram analisadas através do software 3D Endo<sup>™</sup>. A interface desse software apresenta 5 passos a serem seguidos. O primeiro, "Diagnosis & Pathology", permite uma visualização original da imagem e sua delimitação (Fig.2 A). No segundo passo, "3D Tooth Anatomy", o dente a ser analisado é individualizado usando uma ferramenta de corte para eliminar a maior parte das estruturas adjacentes e que não são de interesse (Fig.2 B). Então, no terceiro passo, o operador pode identificar o "sistema de canais" (Fig.2 C) marcando, através dos cortes axiais, o orifício de entrada do canal radicular e o FA de cada dente, gerando linhas automáticas que conectam ambos os pontos. No quarto passo, "3D Canal Anatomy" o operador pode criar pontos intermediários entre as marcações do orifício e do FA, permitindo um refinamento tridimensional da trajetória do canal radicular (Fig.2 D, E). Finalmente, no último passo, "Treatment Plan", o software insere automaticamente um instrumento virtual K-file, seguindo a trajetória do canal até o FA. A angulação de inserção do instrumento no canal radicular está de acordo com o conceito de acesso coronário em linha reta (Fig.2 F, G, H). Então, clicando no botão "Suggest" o comprimento sugerido (3D-CS) é calculado automaticamente (Fig.2 I) e essa medida foi registrada. O observador realizou o ajuste manual da posição do cursor, adaptando-o na borda de referência oclusal (Fig.2 J). Essa medida calculada pelo software foi registrada como comprimento ajustado pelo operador (3D-CAO). Após 30 dias de cada avaliação, todas as mensurações foram repetidas para avaliar a calibração intra-examinador.



**Figura 1.** Imagem 3D (A) e obtenção do comprimento de trabalho através do software OnDemand 3D no corte coronal (B) e sagital (C).



**Figura 2.** Sequência para obter o CT usando o software 3D Endo. (A) Imagem inicial por TCFC e (B) seleção do dente usando uma ferramenta de corte. (C) No corte axial, um ponto azul é usado para localizar a entrada do canal radicular (cervical) e outro o FA, que são conectados automaticamente por uma linha. (D) Refinamento da trajetória do canal em ambos os sentidos. (E) Trajetória do canal radicular representado em 3D através da manipulação da transparência do dente. (F) Vista oclusal mostrando a inserção de um instrumento #15 no interior do canal radicular. (G) Uso das flechas de orientação para permitir uma angulação retilínea de inserção do instrumento, bem como o posicionamento de sua ponta no FA marcando 0.0 mm. (H) Trajetória final, do acesso coronário ao FA. (I-J) Vista vestíbulo-lingual e mesio-distal do comprimento sugerido (3D-CS) e do comprimento ajustado pelo operador (3D-CAO) respectivamente.

## Comprimento real

Os dentes foram removidos da mandíbula, lavados com soro fisiológico e colocados em pequenos recipientes para manter o operador cego em relação as medidas obtidas pela TCFC. Foi realizado o acesso coronário dos dentes e ampliação do terço cervical do canal radicular (SX Protaper Universal, Dentsply-Sirona), usando hipoclorito de sódio 2,5% como solução irrigadora e administrada através de uma agulha 30G (NaviTip; Ultradent Products, South Jordan, UT, EUA). Um instrumento manual de #15 (C-Pilot, VDW, Munich, Alemanha) foi usado para remover tecido pulpar e realizar a patência do canal radicular. O terço apical da raiz foi visualizado sob magnificação de 10x (DF Vasconcellos, Londrina, Brasil) e o instrumento #15 foi introduzido no canal radicular até sua ponta se tornar visível na porção coronal do FA (5, 13). Então, o cursor de borracha foi cuidadosamente ajustado no ponto de referência coronal preparado. A distância entre a ponta do instrumento e a base do cursor de borracha foi medida usando um paquímetro digital de precisão (PD) 0,01mm e registrado como comprimento real do canal radicular (CR).

## Obtenção das medidas eletrônicas

Os dentes foram embebidos em alginato e irrigados com hipoclorito de sódio 2,5%. Para obter a medida eletrônica do comprimento dos dentes foi utilizado o localizador foraminal Root ZX II (J. Morita, Tokyo, Japão) e um dispositivo ajustável, como descrito em estudos prévios (5, 26). Resumidamente, a ponta de um instrumento #15 conectado ao PD de precisão 0,01mm foi posicionada no ponto de referência coronal e o PD foi zerado. O instrumento foi inserido no canal radicular e o localizador foraminal conectado no sistema (o clipe labial foi colocado no alginato e o clipe de suporte preso ao instrumento #15). O instrumento foi conduzido no interior do canal radicular pelo operador até o localizador foraminal acender uma luz na marcação "APEX" permanecendo acesa e estável durante 5 segundos. Então, a distância entre a base do cursor e a ponta do instrumento foi mensurada pelo PD de precisão e a medida registrada como comprimento eletrônico (CE).

### Análise estatística

O nível de significância adotado foi de 5%. O teste de ANOVA foi usado para comparar os valores absolutos. O coeficiente de correlação de Pearson e o intervalo de confiança de 95% foi calculado para comparar as medidas obtidas entre os métodos. A fórmula de Dahlberg e o teste T foram usados para checar a calibração intra-examinador para todas as medidas adquiridas através da TCFC. A diferença entre as medidas obtidas por diferentes métodos e o CR foi atribuída como negativa e positiva para comprimentos baixos e altos, respectivamente. A proporção e a porcentagem de distribuição das diferenças foram analisadas usando o qui-quadrado e o teste Z.

## Resultados

A tabela 1 mostra as médias das medidas dos comprimentos obtidas pelos diferentes métodos. O teste de Levene confirmou homogeneidade (p>.05) e foi aplicado o teste de ANOVA one-way que não mostrou diferença entre os grupos em relação ao comprimento (p>.05), o que foi confirmado pela correlação de Pearson (r > 0,975). O erro de variância entre as medidas obtidas pelo 3D-CS e 3D-CAO foi de 0.253% (fórmula de Dahlberg) e a alta confiabilidade foi confirmada quando se comparou a média das medidas obtidas após 30 dias.

A tabela 2 mostra a distribuição absoluta e de porcentagem da diferença entre as medidas obtidas por diferentes métodos comparadas com as medidas do CR. Foi considerado aceitável as medidas que ficaram dentro da faixa de ±0.5mm do forame apical. O teste qui-quadrado mostrou diferença significativa na distribuição das medidas entre os diferentes métodos (p<.05). Os LFE não apresentaram medições <0.5mm do forame apical, apresentando diferença significativa do 3D-CAO e CC (p<.05). O 3D-CAO e o 3D-CS apresentaram significativamente menos casos entre a faixa +0.5mm até +1mm além do forame apical.

|        | Ν  | Média | DP   | Mínimo | Máximo |
|--------|----|-------|------|--------|--------|
| CR     | 30 | 21.22 | 2.08 | 18.20  | 26.80  |
| 3D-CS  | 30 | 21.09 | 2.07 | 18.25  | 26.80  |
| 3D-CAO | 30 | 20.96 | 2.06 | 18.15  | 26.60  |
| CC     | 30 | 20.97 | 2.05 | 17.82  | 26.43  |
| CE     | 30 | 21.43 | 2.12 | 18.00  | 27.00  |

TABELA 1. Descrição da média do comprimento de trabalho usando diferentes métodos.

(CR) comprimento real, (3D-CS) comprimento sugerido pelo 3D-Endo, (3D-CAO) comprimento ajustado pelo operador no 3D-Endo, (CC) comprimento convencional e (CE) comprimento eletrônico. Não houve diferença estatística entre os grupos (p >.05).

**TABELA 2**. Distribuição absoluta e de porcentagem da diferença entre as medidas obtidas por diversos métodos comparadas com as medidas do CR.

|                       | 3D-CS 3D-CAO     |        | CAO            | CC     |                 | CE     |                 |        |
|-----------------------|------------------|--------|----------------|--------|-----------------|--------|-----------------|--------|
| Distância do CR em mm | n                | (%)    | n              | (%)    | n               | (%)    | n               | (%)    |
| -1.5 to -1.01         | 2 <sup>a</sup>   | (6.7)  | 2 <sup>a</sup> | (6.7)  | 1 <sup>a</sup>  | (3.3)  | 0 <sup>a</sup>  | (0.0)  |
| -1 to -0.51           | 1 <sup>abc</sup> | (3.3)  | 4 <sup>b</sup> | (13.3) | 5 <sup>ab</sup> | (16.7) | 0 <sup>c</sup>  | (0.0)  |
| -0.5 to 0.00          | 19 <sup>a</sup>  | (63.3) | 20ª            | (66.7) | 19 <sup>a</sup> | (63.3) | 13 <sup>a</sup> | (43.3) |
| 0.01 to 0.5           | 7 <sup>abc</sup> | (23.3) | 4 <sup>b</sup> | (13.3) | 3 <sup>ab</sup> | (10.0) | 11 <sup>c</sup> | (36.7) |
| 0.51 to 1             | 1 <sup>a</sup>   | (3.3)  | 0 <sup>a</sup> | (0.0)  | 2 <sup>ab</sup> | (6.7)  | 6 <sup>b</sup>  | (20.0) |

(CR) comprimento real, (3D-CS) comprimento sugerido pelo 3D-Endo, (3D-CAO) comprimento ajustado pelo operador no 3D-Endo, (CC) comprimento convencional e (CE) comprimento eletrônico. Valores negativos indicam posição aquém do comprimento real. Diferentes letras sobrescritas indicam significância estatística na linha (p <.05).

### Discussão

O uso de radiografias periapicais pré-operatórias para se obter o comprimento endodôntico estimado até o ápice radiográfico é rotina na clínica. Entretanto, o forame apical normalmente não coincide com o ápice radicular (2-5). TCFC é mais precisa que as radiografias periapicais para estimar o comprimento de trabalho pré-operatório (7, 16) e oferece mais vantagens na hora de avaliar a anatomia interna do canal radicular, por fornecer imagens tridimensionais. Como a constrição apical só pode ser detectada a partir de cortes histológicos ou pela microtomografia computadorizada (2, 5), deve-se considerar como comprimento de trabalho em imagens obtidas a partir da TCFC, o forame apical (19, 23).

O software 3D Endo<sup>™</sup> desenvolvido para o planejamento de tratamentos endodônticos tem potencial para ler qualquer imagem obtida a partir da TCFC (22). O software apresenta uma sequência de trabalho lógica que orienta o operador a identificar e analisar apenas o dente a ser tratado endodonticamente. Além disso, permite o uso de diferentes cores para identificar a trajetória tridimensional de cada canal radicular (23). Até a publicação desse artigo, essa é a primeira investigação sobre o uso deste software para estimar o CT pré-operatório a partir de imagens obtidas pela TCFC. Portanto, esse estudo foi desenvolvido para avaliar a precisão e a confiabilidade de duas opções de medidas ("Comprimento sugerido" e o "comprimento ajustado pelo operador") fornecidas pelo 3D Endo™, mas também para estabelecer uma comparação com outros métodos, dentre eles um software convencional (OnDemand 3D) e o uso de um localizador foraminal eletrônico (Root ZX II). Foi escolhido trabalhar com dentes extraídos, pois é possível registrar o comprimento real do canal, usando-o como padrão ouro (13), além de permitir o controle de algumas variáveis clínicas como a geração de artefatos, dependendo da posição do paciente e padronização de estruturas anatômicas (10, 16, 25). Deve-se destacar que resultados obtidos a partir de testes em laboratório não devem ser extrapolados para a prática clínica, mas devem ser usados como embasamento para melhor compreensão das vantagens e limitações de novas tecnologias.

No presente estudo, o campo de visão (FOV) e o tamanho de voxel utilizados permitiram visualizar a mandíbula por inteiro, simulando a situação clínica de um paciente que já possuía a imagem feita por TCFC por outra razão de diagnóstico. Para avaliação endodôntica, usualmente, um FOV e voxel size pequenos são preferíveis, com o objetivo de reduzir radiação, obter maior resolução espacial e melhorar a precisão das medidas (8, 10, 21, 27). Entretanto, estudos com análises geométricas do sistema de canais radiculares e a determinação do CT reportam como confiáveis as medidas, usando um voxel size de até 0.2mm<sup>3</sup> (10, 16). Consequentemente, os presentes resultados mostraram uma alta correlação entre todas as medidas de TCFC em comparação com o comprimento real do canal.

Na literatura o comprimento do canal radicular obtido por TCFC tende a ser menor do que o comprimento real do canal, variando entre uma faixa de -0,02 até -0,59mm (11, 13, 14, 19, 21). Um estudo (11) mostrou que a subestimação de medidas obtidas a partir da TCFC comparada com cortes histológicos varia dependendo dos procedimentos de segmentação e aquisição. Os resultados obtidos nesse estudo, para os comprimentos médios, estavam dentro dos intervalos relatados: - 0,25 mm para o CC, - 0,13 mm para 3D-CS e -0,26 mm para 3D-CAO. Em relação à porcentagem de medidas menores que -0,5mm da FA, foi encontrado 10% para 3D-CS e 20% para 3D-CAO e CC, enquanto o intervalo relatado é de 17% a 50% (13, 19, 21). As discrepâncias entre os estudos podem estar correlacionadas com os diferentes sistemas de TCFC e os diversos parâmetros de exposição (11, 21, 24, 28).

A precisão das medidas obtidas por TCFC parece estar também relacionada aos métodos e às capacidades do software (11, 16). Em estudos anteriores, utilizando o software convencional OnDemand (Fig. 1), o CC foi obtido num plano que mostra simultaneamente a referência coronal e o FA (17, 18, 20, 21). No entanto, a confiabilidade dessas medidas é altamente dependente das habilidades do operador em selecionar a visão sagital que pode representar melhor o comprimento do canal e ainda permitir melhor identificação dos pontos de referência (16, 24). Nesse sentido, a trajetória semi-automática do software 3D Endo<sup>™</sup> poderia potencialmente melhorar a reprodutibilidade das medidas (23). No entanto, observou-se uma alta reprodutibilidade independentemente do software. Possíveis limitações de nossa investigação foram a padronização de amostras e "expertise" do operador; entretanto, canais retos com forame axial e cúspide regularizada pode ter reduzido o erro de medição. Pesquisas futuras devem avaliar o comprimento dos canais radiculares em dentes com múltiplas raízes, com canais curvos e também comparar os resultados entre diferentes níveis de experiência do operador.

A maioria dos métodos descritos previamente para mensuração dos canais radiculares a partir de imagens obtidas por TCFC usaram uma linha seguindo a trajetória do canal, desde o FA até a referência coronal, sem considerar a localização do acesso (13-15, 21). Esse método foi usado no presente estudo para investigar o CC (Fig.1 B, C). Diferentemente, o 3D Endo™ permitiu que o operador localizasse virtualmente a cavidade de acesso endodôntico, logo o comprimento foi medido usando um instrumento virtual cuja trajetória estava em conformidade com a posição de acesso realizada (Fig.2 H). Essa característica pode aumentar a precisão da determinação do comprimento de trabalho, porque simula uma situação real, uma vez que a localização do acesso pode mudar a angulação do instrumento e a sua relação com o ponto de referência oclusal. Isso pode estar correlacionado com a alta porcentagem de aceitabilidade das medidas obtidas pelo 3D Endo™, sendo de 86% para 3D-CS e 80% para 3D-CAO, seguido pelo CC com uma porcentagem de 73,3%. Os presentes resultados não mostraram diferença estatística entre os dois softwares (p>.05), eles estão acima da faixa de porcentagens reportadas na literatura, entre 46% e 70% (13, 19, 21), para medidas entre ±0.5mm do forame apical.

Após investigações anteriores (14, 21), o CC foi realizado pela média aritmética entre os comprimentos obtidos pelos cortes coronal e sagital (Fig.1 B, C), método que provavelmente aumenta a precisão porque também considera o aspecto MD da anatomia do canal (15, 23). No entanto, mesmo usando ambas as visualizações, essa abordagem está medindo o canal em duas dimensões da TCFC. Uma análise morfológica da posição da articulação temporomandibular (29) mostrou que as medidas realizadas em modelos espaciais tridimensionais foram mais precisas do que usando distâncias lineares nas fatias 2D de imagens de TCFC. Da mesma forma, no software 3D Endo™, a trajetória final é uma imagem tridimensional; o operador pode realizar ajustes para centralizar a linha no canal

de acordo com qualquer visualização (Fig.2 D). Esta linha pode então ser visualizada alterando a transparência do modelo virtual do dente (Fig.2 E). Os resultados (Tabela 1) mostraram que entre as medidas obtidas a partir de imagens da TCFC, o 3D-CS foi o mais preciso, mas não estatisticamente diferente (p > .05). Outras pesquisas devem avaliar a influência do uso dessa medida tridimensional do canal radicular em canais curvos.

Para as medições do CT no 3D Endo<sup>™</sup>, o operador pode ajustar tanto a distância apical (Fig.2 F, G) quanto a posição da referência coronal (22). No presente estudo, a distância apical de 0,0 mm foi selecionada para as duas funções do software 3D Endo<sup>™</sup>, pois o padrão ouro foi o comprimento real até o FA. Portanto, a principal diferença entre 3D-CS e 3D-CAO foi ajustar a posição do cursor de borracha virtual na referência coronal. Os resultados mostraram que os ajustes realizados pelo operador (3D-CAO) reduziram o comprimento automático (3D-CS) de 0 mm para 0,2 mm, o que pode ser considerado clinicamente irrelevante (5, 21, 26, 30-32). Embora não tenha havido diferença estatística, o 3D-CAO resultou em menos casos que ultrapassaram o FA. Portanto, parece apropriado que, ao usar o software 3D Endo<sup>™</sup>, o clínico deva ajustar ou confirmar a posição do cursor de borracha virtual de acordo com sua referência coronal.

Estudos clínicos anteriores mostraram que as medidas do CT obtida nas imagens de TCFC foi semelhante as do LFE (14, 17, 18), enquanto que as avaliações in vitro que usaram o comprimento real do dente como padrão ouro descobriram que o LFE foi mais preciso do que a TCFC (16, 19). Diferenças entre os estudos podem ser correlacionadas com o desenho do estudo, tipo de dentes, pontos anatômicos e diferentes dispositivos (14, 17, 19, 32). No presente estudo, o Root ZX II foi escolhido por causa de sua alta precisão e reprodutibilidade, resultados que são bem sedimentados na literatura (4, 6, 14, 30-35) e o FA foi usado como referência porque é uma estrutura anatômica constante (5, 26, 30- 33) que pode ser localizada nos exames de TCFC (9, 23).

O uso do LFE não resultou em medidas menores que 0,5 mm do FA, sendo significativamente diferente do 3D-CAO e CC. Como subestimar o limite apical impede a desinfecção adequada do canal radicular (1, 2), os resultados atuais indicam que os comprimentos pré-operatórios da TCFC devem sempre ser

clinicamente confirmados com um LFE (14, 16, 19). Por outro lado, o CE resultou em medições superestimadas no intervalo de 0,5 a 1 mm além do FA (p < .05). Isso é explicado pela seleção da marca "APEX", que localiza o FA com alta precisão, mas requer um recuo de cerca de 0,5 a 1 mm para estabelecer um limite apical adequado (5, 30-32).

## Conclusão

Para os casos em que já existam imagens prévias de TCFC, os resultados atuais suportam seu uso para a estimativa pré-operatória do CT (13-15, 20, 21). Ambas as funções para determinação do CT do 3D Endo ™ foram confiáveis e similares a um software convencional . No entanto, é necessário o uso dos LFE para confirmar e ajustar o limite apical, uma vez que a determinação do CT pode sofrer pequenas variações durante o procedimento endodôntico dependendo da situação clínica (3, 34, 35).

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## **ARTIGO EM INGLÊS**

## Title page

The Accuracy of a New Cone-Beam Computed Tomographic Software in the Preoperative Working Length Determination. Ex Vivo **AUTHORS:** 

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## Abstract

Introduction: This study investigates the accuracy of 3D Endo<sup>™</sup> software (Dentsply/Sirona) to determine the working length (WL) when using preoperative cone-beam computed tomography (CBCT) scans of extracted teeth, compared to a conventional CBCT software and an electronic apex locator (EAL). Methods: CBCT scans of 30 premolars were obtained. Using the OnDemand3D<sup>™</sup> software, the measurement obtained from the coronal reference to the apical foramen (AF) was recorded as the conventional CBCT length (CL). Then, using the 3D Endo™ software, the suggested length (3D-SL) and the operator-adjusted length (3D-OL) were obtained. Teeth were accessed, and the actual length (AL) was measured. Finally, the teeth were embedded in alginate to obtain the electronic lengths (EL), using the EAL Root ZX (J. Morita). The means of the absolute values and the percentages of distribution of the tested measurement methods were compared to the AL. **Results**: No difference was found regarding the mean measurements (ANOVA p >.05). All the CBCT measurements presented a high reliability (Dahlberg's formula). The measurements within  $\pm 0.5$  mm range from the AF were 86.6% for the 3D-SL, 80% for 3D-OL and EL, and 73.3% for the CL. The EL presented significantly fewer underestimated measurements (p <.05). The 3D-OL and 3D-SL presented significantly fewer measurements beyond the AF (p < .05). **Conclusions**: The preoperative WL determination using the 3D Endo<sup>™</sup> was reliable and similar to conventional CBCT software. However, the combined use of CBCT with an EAL is required to increase the accuracy in the location of the AF.

**Key Words:** 3D endo, cone-beam computed tomography, electronic Apex locator, endodontics, working length

## Introduction

The determination of a proper apical limit is critical for the success of endodontic treatment (1, 2). Under- or overestimation of the working length (WL) might result, respectively, in insufficient disinfection or damage to the periapical tissues (1, 2). The apical foramen (AF) is where the canal exits at the root surface, and the apical constriction (AC) is the smallest diameter of the canal. The AC is usually located 0.5–1 mm short of the AF, and it is considered the ideal endpoint for endodontic procedures (2).

Periapical radiographs and electronic apex locators (EALs) are currently the most used methods for intraoperative determination of the WL. EALs are more precise and reliable than radiographs (3, 4), but its performance might be affected by different situations such as anatomic complexities, lack of patency, or metallic restorations (3-6). On the other hand, limitations of conventional radiography are largely related to its bi-dimensional nature, which prevents accurate WL determination in cases with curvatures in the buccolingual (BL) plane, lateral foramen, distortions, superimposition of anatomical structures, and difficulties with landmark identification (4, 7).

Cone-beam computed tomography (CBCT) is a contemporary radiological imaging system that is useful in providing reliable anatomic information in three dimensions for diagnosis and treatment planning before endodontic therapy (8-12). A preexisting CBCT for any indication in dentistry might be potentially used for preoperative estimation of the WL (13-15). However, there is no consensus in the literature regarding the accuracy of CBCT measurements when compared to the traditional WL determination methods, such as EALs and radiographs (7, 13-19).

The discrepancy among different studies could be related to the methods used to obtain the WL in the scans, which rely on the measuring tools available in the CBCT software programs. Most of this software present a ruler tool that can be used for measuring any given distances, but usually in a selected bi-dimensional plane. In other words, the operator needs to locate the longitudinal view that can better represent the entire length of the canal to draw a line from the coronal reference to the apical foramen (16-18, 20). For curved canals, it has been suggested to use a segmented line to follow a curved canal trajectory in the different planes (14, 15, 19, 21) or to draw a horizontal line at the coronal reference point and connect it with the foramen in the other plane (20). In addition, some studies used the mean between the lengths from mesiodistal (MD) and buccolingual (BL) views in the CBCT scans as the WL measurement (14, 21). This variability in the methods might affect the repeatability and make it difficult to compare results from different studies (7, 16, 20).

Recently, the 3D Endo<sup>™</sup> software (Dentsply/Sirona, Wels bei Salzburg, Austria) has been developed for the specific treatment planning of endodontic procedures (22). It presents an intuitive interface in which the clinician can follow steps for the identification and measurement of the canals, as well as the virtual planning of the access cavity, apical limit, and file selection for shaping procedures. A recent study reported that this software enhances the three-dimensional visualization of the canal complexities such as curvatures and confluences (23). An innovative feature of this software is the semi-automated detection of the root canal trajectory; after identifying the orifice and apical foramen (AF), an automated line connecting them is generated, which can be adjusted to follow the canal trajectory

in three dimensions. Using this trajectory as a reference, a virtual endodontic file can be used to estimate the WL, using either an automatic suggestion or manual adjustment by the clinician. This semi-automated detection of the canal trajectory has the potential to minimize subjective errors related to the operator's skills (21, 23, 24).

Although this software is designed for clinical use, it requires an initial laboratory investigation to validate these virtual WL estimations compared with a gold standard, which in this case is the actual extracted tooth length (13). In addition, it is also relevant to verify whether the semi-automated tools offer an advantage compared to the use of conventional software for CBCT analysis. Thus, this ex vivo study was designed to investigate the accuracy of the new 3D Endo software™, a conventional CBCT software (OnDemand3D™, Cybermed, Seoul, Korea), and an EAL (Root ZX, J. Morita, Tokyo, Japan) in the WL determination.

### **Materials and Methods**

This study was approved by the local ethical committee (protocol 2.348.485). Ninety extracted human single-rooted mandibular premolar teeth stored in 0.1% thymol solution and one dry mandible were obtained from the School of Health and Biosciences of the Pontifical Catholic University (Curitiba, Brazil). The teeth were evaluated under an operating microscope at 10x magnification (DF Vasconcellos, Londrina, Brazil) to exclude roots presenting cracks, calcified canals, immature apices, resorptive defects, caries, previous root canal access or filling material, and lateral foramina (6). The teeth were scanned by means of cone-beam computed tomography (CBCT) to evaluate and standardize the anatomical parameters. CBCT scans were performed using the Scanora 3D (Soredex, Tuusula, Finland) at 120 kVp, 12.5 mA, field of view (FOV) of 75 x 100 mm, and 0.2mm voxel. Thirty standardized teeth presenting with Vertucci type I configuration were obtained. The selected teeth were washed in saline and buccal cusps were flattened to be used as a consistent and reproducible coronal reference for all the measurements.

### **CBCT** measurements

The teeth were numbered and randomly divided to be scanned 4 teeth at a time. For length measurement CBCT scans, each tooth was placed in a prepared, empty mandibular premolar socket of the dry mandible (16). The mandible was fixed at the base of a plastic container filled with water to simulate soft tissue (25) and scanned by means of CBCT (Scanora 3D, Soredex Tuusula, Finland) at 90 kV, 13 mA, FOV of 60 x 60 mm, and 0.133 mm<sup>3</sup> voxel size.

All CBCT scans were analyzed by 1 experienced endodontist. The images were manipulated using a PC running Microsoft<sup>®</sup> Windows XP Professional (Microsoft Corp, Redmond, WA), on a 22.5-inch flat-screen monitor (resolution 1920 x1200 pixels).

In the first section, the images were analyzed using the CBCT OnDemand3D<sup>™</sup> software. The selected tooth was vertically positioned and slightly rotated to obtain a single longitudinal slice that best represented the whole length of the canal, in both the BL and MD views (19). A measuring line was traced from the occlusal reference (flattened buccal cusp) to the apical foramen (AF), centered in the canal, following any visible deviation (Fig.1 A-C). The average between BL and MD measurements was recorded as the conventional CBCT length (CL).

After 2 weeks, the 3D Endo<sup>™</sup> software was used in the same scans. The interface of this program presents 5 major steps. The first, "Diagnosis & Pathology", allows the traditional visualization of CBCT images and rendering (Fig.2 A). In the second step, "3D Tooth Anatomy", the tooth is individualized by using a crop tool to remove most of the surrounding tissues (Fig. 2 B). Then, the operator can identify the "Canal System" (Fig.2 C) by selecting, in the axial images, the location of the orifice and AF of each canal, followed by an automatic line that connects both landmarks. In the fourth step, "3D Canal Anatomy", the operator may use any of the anatomical planes to create midpoints and drag the line to be positioned into the center of the canal, resulting in a trajectory that follows the 3D curvatures of the root canal (Fig.2 D-E). Finally, in the fifth step, "Treatment Plan", after the software automatically inserts a virtual K-file into the canal trajectory, the apical position is set to AF. In our study, the coronal angulation of the file was positioned according to the concept of a straight-line endodontic access (Fig.2 F-G). After clicking the Suggest button, the suggested length (3D-SL) was calculated (Fig.2 I). This length was recorded, then the virtual rubber stopper was manually adjusted to the coronal reference (Fig.2 J). The new length of the virtual file calculated by the software was recorded as the operator-adjusted working length (3D-OL). After 30 days, all the CBCT measurements were repeated to check the intra-examiner reliability.

## **Actual measurements**

The teeth were removed from the mandibles, cleaned with saline, and placed in recoded containers to keep the operator blinded to the CBCT measurements. The teeth were accessed and the cervical third of the root canals was preflared (SX

rotary file, Dentsply-Sirona), using 2.5% sodium hypochlorite as the irrigating solution, which was delivered using a 30G side-vented needle (NaviTip; Ultradent Products, South Jordan, UT, USA). A manual size 15 file (C-Pilot, VDW, Munich, Germany) was used to remove pulp tissue and verify patency. The apical third of the roots were visualized under 10x magnification (DF Vasconcellos, Londrina, Brazil), and the 15 K-file was introduced into the root canal until the tip became visible at the most coronal border of the AF opening (5, 13). Then, the rubber stop was carefully adjusted to the reference point (flattened buccal cusp). The distance between the file tip and the rubber stop was measured by using a digital caliper (DC) to a 0.01 mm precision and recorded as the actual root canal length (AL). This measurement (AL) served as the gold standard for the other measurements obtained in this study.

### **Electronic measurements**

The electronic measurements were obtained using a mounting model as previously described (5, 26). Briefly, the teeth were embedded in freshly mixed alginate and the canals were irrigated with 2.5% sodium hypochlorite. A 15 K-file connected to a DC with 0.01 mm precision was positioned at the coronal reference (flattened buccal cusp) and the DC was set to 0. The file was then inserted into the root canal and the Root ZX EAL was connected to the system by placing the lip clip in the alginate and the file holder on the 15 K-file. The file was advanced until the flashing APEX mark remained stable for 5 seconds. The distance traveled by the file inside the canal, as shown by the DC, was recorded as the electronic length (EL).

### Statistical analysis

Data obtained from all measurements was statistically analyzed with the significance set at .05. The ANOVA test was used to compare the absolute values. The Pearson correlation coefficient and 95% confidence intervals were calculated to compare the measurement methods. Dahlberg's formula and *t*-test were used to check the intra-examiner reliability for all the CBCT measurements. The difference between the measurements obtained by the different methods and the AL was assigned as negative and positive for lower and higher lengths, respectively. The proportion and percentages of the distribution of the differences were analyzed using the chi-square and proportion *z*-tests.

## Results

Table 1 presents the mean and standard deviation for the length measurements. The Levene test confirmed the assumption of homogeneity (p >. 05). The one-way analysis of variance test showed no difference among the groups regarding the mean length (p >.05). This was confirmed by the Pearson correlation (r >0.975). The variance error of 3D-SL and 3D-OL measurements was 0.253% (Dahlberg's formula), and the high reliability was confirmed when comparing the mean measurements obtained after 30 days (*t*-test, p >.05).

Table 2 shows the percentage distributions of the difference between the measurements obtained by the different methods compared with the respective visual length (AL). The measurements within  $\pm 0.5$  mm of the AF were considered acceptable. The chi-square test showed a significant difference in the distribution

of the different methods (p < .05). The EL presented no measurements <0.5 mm for the AF, which was significantly different from the 3D-OL and CL (p < .05). The 3D-OL and 3D-SL presented significantly fewer cases in the range from 0.5-1 mm beyond the AF.

## Discussion

The use of preoperative periapical radiographs to obtain the estimated endodontic length up to the radiographic apex is a routine clinical practice. However, the AF does not usually coincide with the radiographic apex (2-5). CBCT imaging has proven to be more accurate than periapical radiographs for preoperative WL length estimation (7, 16) and offers the advantage of assessing the anatomy of the canal in 3 dimensions. Because the AC can only be detected in histologic cuts or by using high-resolution micro-computed tomographic imaging (2, 5), the WL obtained in CBCT scans should consider the AF as a reference (19, 23).

3D Endo<sup>TM</sup> is a software developed for specific planning of endodontic procedures that can potentially be used with any set of CBCT scans (22). It presents a logical workflow that guides the operator and allows the use of color codes for each canal to identify the canal trajectory in three dimensions (23). To the best of our knowledge, this is the first investigation of the use of this software for preoperative WL estimation by using CBCT images. Thus, this study was designed to evaluate the accuracy and the reliability of the two measuring options available in the 3D Endo<sup>TM</sup> interface (suggested and operator-adjusted), but also to establish a comparison to other methods, including conventional CBCT software (OnDemand3D<sup>TM</sup>) and the use of an EAL. The use of an *ex vivo* model was chosen because it allows use of the actual length of the canal as a gold standard (13) and control of some of the clinical variables such as artifacts that might occur from position and motion of the patient, beam hardening from other materials, or noise from other anatomic structures (10, 16, 25). It should be noted that the results obtained in a laboratory setting should not be directly extrapolated to a clinical situation, but used as a reference to understand the advantages and limitations of new technologies.

In this study, the FOV and voxel sizes allowed visualization of the entire mandible, mimicking a diagnostic CBCT that could have been taken for any other purpose. For endodontic evaluation, a smaller FOV and voxel size are preferable, aiming to reduce the radiation, obtain a higher spatial resolution, and improve the accuracy of the measurements (8, 10, 21, 27). However, the geometrical analysis of the root canal system and WL determination have been reported to be reliable up to a voxel size of 0.2 mm<sup>3</sup> (10, 16). Accordingly, the present results showed a high correlation between all the CBCT measurements and the actual canal length.

In the literature, the root canal measurements obtained from CBCT tend to be shorter than the actual lengths, ranging from -0.02 to -0.59mm (11, 13, 14, 19, 21). A previous investigation (11) showed that the underestimation of the CBCT measurements, compared to histologic cuts, varied depending on the segmentation procedures and acquisition settings. Present results for mean lengths were within reported ranges: -0.25 mm for the CL, -0.13 mm for the 3D-SL, and -0.26 mm for the 3D-OL. Regarding the percentage of measurements shorter than -0.5 mm from the AF, 10% was found for 3D-SL and 20% for both 3D-OL and CL in the present study, whereas the reported range vary from 17% to 50% (13, 19, 21). The

discrepancies among the studies might be correlated to the different CBCT systems and the diverse exposure parameters (11, 21, 24, 28).

The accuracy of the CBCT measurements seems also to be related to the methods and the software's capabilities (11, 16). Following previous studies, when using the conventional OnDemand3D<sup>™</sup> software (Fig. 1), the CL was obtained in a plane showing the coronal reference and the AF simultaneously (17, 18, 20, 21). These measurements depend highly on the operators' skills while selecting the view that can represent the entire length of the canal while identifying these landmarks (16, 24). In this sense, the semi-automated trajectory of the 3D Endo<sup>™</sup> software can be suggested to improve the repeatability of these measurements (23). However, results showed that a high repeatability was observed regardless of the software. Possible limitations of our investigation were the standardization of samples and the expertise of the operator, however, the use of straight roots with axial foramen and flattened cusp probably reduced the measurement error. Future research should evaluate the WL determination in multiple-rooted teeth, curved canals, and the results from different levels of operators' experience.

Most of the previously described methods for measuring the root canals in CBCT images use a quantitative line following the canal pathway, from the AF up to the coronal reference, without considering the location of the access (13-15, 21). This method was used in the present investigation for the CL (Fig. 1-B, C). On the other hand, the 3D-Endo software allows the operator to locate the endodontic access virtually, then the length is measured by using a virtual file whose trajectory complies with the canal pathway and the determined access position (Fig. 2-H). This feature is likely to increase the accuracy of the WL because, in a real situation,

the location of the access potentially changes the angulation of the file and its relation to the coronal reference. This might be correlated with the higher percentage of acceptable measurements of the 3D Endo<sup>TM</sup>, 86% and 80%, respectively, for 3D-SL and 3D-OL, followed by the CL at 73.3%. Although present results showed no statistical difference between the two software programs (p >.05), they were above the percentages reported in the literature, ranging from 46% to 70% (13, 19, 21) of WL measurements of ±0.5 mm within the AF.

Following previous investigations (14, 21), the CL was the arithmetic mean between the BL and MD lengths (Fig. 1-B, C), which is likely to increase the accuracy because it also considers the MD aspect of the canal anatomy (15, 23). However, even using both views, this approach is measuring the canal in two 2D projections of the CBCT scan. A morphologic analysis of the temporomandibular joint position (29) showed that the measurements performed in three-dimensional spatial models were more accurate than using linear distances in the 2D slices of CBCT images. Similarly, in the 3D Endo™ software, the final trajectory is a threedimensional rendering: the operator can perform adjustments to position the line centered in the canal according to any view (Fig. 2-D). This segmented line can then be visualized by changing the transparency of the virtual model of the tooth (Fig. 2-E). The present results (Table 1) showed that among the CBCT measurements, the 3D-SL was the most accurate but not statistically different (p >.05). Further research should evaluate the influence of using this threedimensional root canal measurement in curved canals.

For the WL measurements in the 3D Endo<sup>™</sup>, the operator can adjust both the apical distance (Fig. 2-F,G) and the position of the coronal reference (22). In

the present study, the 0.0 mm apical distance was selected for both 3D Endo<sup>™</sup> WL functions because the gold standard was actual length up to the AF. Therefore, the main difference between 3D-SL and 3D-OL was adjusting the position of the virtual rubber stopper to the coronal reference. The results showed that adjustments performed by the operator (3D-OL) reduced the automatic length (3D-SL) from 0 mm up to 0.2 mm, which might be considered clinically irrelevant (5, 21, 26, 30-32). Although there was no statistical difference, 3D-OL resulted in fewer cases beyond the AF. Therefore, it seems appropriate that when using the 3D Endo<sup>™</sup> software, the clinician should adjust or confirm the position of the virtual rubber stopper according to its preferred coronal reference.

Previous clinical studies have found that the WL measurement obtained in the CBCT images was similar to the EAL (14, 17, 18), whereas *in vitro* evaluations that used the actual length of the tooth as a gold standard have found that the EAL was more accurate than CBCT (16, 19). Differences among studies can be correlated with the study design, type of teeth, anatomic landmarks, and different devices (14, 17, 19, 32). In the present study, the Root ZX was chosen because of its well-documented accuracy and repeatability (4, 6, 14, 30-35) and the AF was used as reference because it is a constant landmark (5, 26, 30-33) that can be located in the CBCT scans (9, 23).

The use of an EAL did not result in measurements shorter than 0.5 mm from the AF, being significantly different from 3D-OL and CL. Because underestimation of the apical limit prevents proper disinfection of the canal (1, 2), present results indicate that the preoperative CBCT lengths should always be clinically confirmed with an EAL (14, 16, 19). On the other hand, the EL resulted in more over-extended

measurements in the range of 0.5–1 mm beyond the AF (p < .05). This is explained by the selection of the APEX mark, which locates the AF with high precision but requires withdrawal of about 0.5–1 mm to establish a proper apical limit (5, 30-32).

## Conclusion

For the cases in which a previous CBCT is already available, present results support its use for the preoperative WL estimation (13-15, 20, 21). Both functions for WL determination by the 3D Endo<sup>TM</sup> were reliable and similar to conventional CBCT software. Nevertheless, the use of an EAL is required to confirm and adjust the apical limit, because the WL is subjected to small changes during endodontic procedures (3, 34, 35).

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## ANEXO

Parecer do comitê de ética

## Artigo publicado – Journal of Endodontics





## PARECER CONSUBSTANCIADO DO CEP

## DADOS DO PROJETO DE PESQUISA

PUCPR

Título da Pesquisa: Avaliação do comprimento de trabalho de canais radiculares em dentes humanos. Um estudo ex vivo.

Pesquisador: Everdan Carneiro Área Temática: Versão: 1 CAAE: 79051917.1.0000.0020 Instituição Proponente: Pontifícia Universidade Católica do Parana - PUCPR Patrocinador Principal: Financiamento Próprio

## DADOS DO PARECER

Número do Parecer: 2.348.485

### Apresentação do Projeto:

Estudo de avaliação do comprimento retrabalho de canais radicares em dentes humanos, um estudo ex vivo, que será conduzido pelo pesquisador com custos próprios.

## **Objetivo da Pesquisa:**

O objetivo deste trabalho é avaliar, ex vivo, a eficácia do software 3D ENDO™ na determinação do comprimento de trabalho do canal radicular.

## Avaliação dos Riscos e Benefícios:

Não há riscos ou benefícios a serem considerados neste parecer.

#### Comentários e Considerações sobre a Pesquisa:

Noventa pré-molares inferiores, obtidos no Banco de Dentes da PUCPR, serão analisados através do exame clínico e tomográfico.

## Considerações sobre os Termos de apresentação obrigatória:

O pesquisador apresentou a devida autorização da responsável pela Clínica Odontológica da Pontifícia Universidade Católica do Paraná, local onde será realizada a pesquisa.

## **Recomendações:**

Não há recomendações.



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Continuação do Parecer: 2.348.485

## Conclusões ou Pendências e Lista de Inadequações:

Projeto Aprovado.

## Considerações Finais a critério do CEP:

## Este parecer foi elaborado baseado nos documentos abaixo relacionados:

| Tipo Documento      | Arquivo                     | Postagem   | Autor            | Situação |
|---------------------|-----------------------------|------------|------------------|----------|
| Informações Básicas | PB_INFORMAÇÕES_BÁSICAS_DO_P | 08/10/2017 |                  | Aceito   |
| do Projeto          | ROJETO_999516.pdf           | 16:26:05   |                  |          |
| Declaração de       | Infraestrutura.jpg          | 08/10/2017 | Everdan Carneiro | Aceito   |
| Instituição e       |                             | 16:12:30   |                  |          |
| Infraestrutura      |                             |            |                  |          |
| Projeto Detalhado / | projeto_mestrado.doc        | 24/09/2017 | Everdan Carneiro | Aceito   |
| Brochura            |                             | 21:44:07   |                  |          |
| Investigador        |                             |            |                  |          |
| Folha de Rosto      | Folha_de_rosto.pdf          | 24/09/2017 | Everdan Carneiro | Aceito   |
|                     |                             | 21:42:00   |                  |          |

#### Situação do Parecer:

Aprovado

Necessita Apreciação da CONEP:

Não

CURITIBA, 25 de Outubro de 2017

Assinado por: NAIM AKEL FILHO (Coordenador)

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*c*orno7*o*;

## The Accuracy of a New Cone-beam Computed Tomographic Software in the Preoperative Working Length Determination *Ex Vivo*

Check for updates

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#### Abstract

Introduction: This study investigates the accuracy of 3D Endo software (Dentsply Sirona, Salzburg, Austria) to determine the working length when using preoperative cone-beam computed tomographic (CBCT) scans of extracted teeth, compared with conventional CBCT software and an electronic apex locator (EAL). Methods: CBCT scans of 30 premolars were obtained. Using OnDemand3D software (Cybermed, Seoul, Korea), the measurement obtained from the coronal reference to the apical foramen (AF) was recorded as the conventional CBCT length. Then, using 3D Endo software (Dentsply Sirona), the suggested length (3D-SL) and the operator-adjusted length (3D-OL) were obtained. Teeth were accessed, and the actual length was measured. Finally, the teeth were embedded in alginate to obtain the electronic length (EL) using the EAL Root ZX (J Morita, Tokyo, Japan). The means of the absolute values and the percentages of distribution of the tested measurement methods were compared to the actual length. Results: No difference was found regarding the mean measurements (analysis of variance, P > .05). All the CBCT measurements presented a high reliability (Dahlberg's formula). The measurements within a  $\pm 0.5$ -mm range from the AF were 86.6% for the 3D-SL, 80% for the 3D-OL and EL, and 73.3% for the CBCT length. The EL presented significantly fewer underestimated measurements (P < .05). The 3D-OL and 3D-SL presented significantly fewer measurements beyond the AF (P < .05). **Conclusions:** The preoperative working length determination using 3D Endo was reliable and similar to conventional CBCT software. However, the combined use of CBCT with an EAL is required to increase the accuracy in the location of the AF. (J Endod 2018;44:1024-1029)

#### **Key Words**

3D endo, cone-beam computed tomography, electronic apex locator, endodontics, working length

The determination of a proper apical limit is critical for the success of endodontic treatment (1, 2). Under- or overestimation of the working length (WL) might result, respectively, in insufficient disinfection or damage to the periapical

#### Significance

3D Endo is CBCT software dedicated to endodontics that presents automated functions for preoperative working length determination. It was considered reliable and similar to conventional CBCT software, but measurements should be clinically confirmed using an apex locator.

tissues (1, 2). The apical foramen (AF) is where the canal exits at the root surface, and the apical constriction (AC) is the smallest diameter of the canal. The AC is usually located 0.5–1 mm short of the AF, and it is considered the ideal end point for endodontic procedures (2).

Periapical radiographs and electronic apex locators (EALs) are currently the most used methods for intraoperative determination of the WL. EALs are more precise and reliable than radiographs (3, 4), but their performance might be affected by different situations such as anatomic complexities, lack of patency, or metallic restorations (3-6). On the other hand, limitations of conventional radiography are largely related to its bidimensional nature, which prevents accurate WL determination in cases with curvatures in the buccolingual (BL) plane, a lateral foramen, distortions, superimposition of anatomic structures, and difficulties with landmark identification (4, 7).

Cone-beam computed tomographic (CBCT) imaging is a contemporary radiologic imaging system that is useful in providing reliable anatomic information in 3 dimensions for diagnosis and treatment planning before endodontic therapy (8-12). A preexisting CBCT scan for any indication in dentistry might be potentially used for preoperative estimation of the WL (13-15). However, there is no consensus in the literature regarding the accuracy of CBCT measurements when compared with the traditional WL determination methods, such as EALs and radiographs (7, 13-19).

The discrepancy among different studies could be related to the methods used to obtain the WL in the scans, which rely on the measuring tools available in the CBCT software programs. Most of this software presents a ruler tool that can be used for

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## **Basic Research—Technology**



Figure 1. The 3D rendering (A) and working length obtained using OnDemand3D software in the (B) BL and (C) MD views.

measuring any given distances but usually in a selected bidimensional plane. In other words, the operator needs to locate the longitudinal view that can better represent the entire length of the canal to draw a line from the coronal reference to the apical foramen (16-18, 20). For curved canals, it has been suggested to use a segmented line to follow a curved canal trajectory in the different planes (14, 15, 19, 21) or to draw a horizontal line at the coronal reference point and connect it with the foramen in the other plane (20). In addition, some studies used the mean between the lengths from the mesiodistal (MD) and BL views in the CBCT scans as the WL measurement (14, 21). This variability in the methods might affect the repeatability and make it difficult to compare results from different studies (7, 16, 20).

Recently, 3D Endo software (Dentsply Sirona, Salzburg, Austria) has been developed for specific treatment planning of endodontic procedures (22). It presents an intuitive interface in which the clinician can follow steps for the identification and measurement of the canals as well as virtual planning of the access cavity, apical limit, and file selection for shaping procedures. A recent study reported that this software enhances the 3-dimensional (3D) visualization of the canal complexities such as curvatures and confluences (23). An innovative feature of this software is the semiautomated detection of the root canal trajectory; after identifying the orifice and AF, an automated line connecting them is generated, which can be adjusted to follow the canal trajectory in 3 dimensions. Using this trajectory as a reference, a virtual endodontic file can be used to estimate the WL, using either an automatic suggestion or manual adjustment by the clinician. This semiautomated detection of the canal trajectory has the potential to minimize subjective errors related to the operator's skills (21, 23, 24).

Although this software is designed for clinical use, it requires an initial laboratory investigation to validate these virtual WL estimations compared with the gold standard, which in this case is the actual extracted tooth length (13). In addition, it is also relevant to verify whether the semiautomated tools offer an advantage compared with the use of conventional software for CBCT analysis. Thus, this *ex vivo* study was designed to investigate the accuracy of the new 3D Endo software, conventional CBCT software (OnDemand3D; Cybermed, Seoul, Korea), and an EAL (Root ZX; J Morita, Tokyo, Japan) in WL determination.

#### **Materials and Methods**

This study was approved by the local ethics committee (protocol 2.348.485). Ninety extracted human single-rooted mandibular premolar teeth stored in 0.1% thymol solution and 1 dry mandible were obtained from the School of Health and Biosciences of the

Pontifical Catholic University, Curitiba, Brazil. The teeth were evaluated under an operating microscope at  $10 \times$  magnification (DF Vasconcellos, Londrina, Brazil) to exclude roots presenting cracks, calcified canals, immature apices, resorptive defects, caries, previous root canal access or filling material, and lateral foramina (6). The teeth were scanned by means of CBCT imaging to evaluate and standardize the anatomic parameters. CBCT scans were performed using the Scanora 3D (Soredex, Tuusula, Finland) at 120 kVp, 12.5 mA, field of view (FOV) of 75 × 100 mm, and 0.2-mm voxel size. Thirty standardized teeth presenting with Vertucci type I configuration, an apical curvature <10°, and an apical diameter up to 0.3 mm were obtained. The selected teeth were washed in saline, and buccal cusps were flattened to be used as a consistent and reproducible coronal reference for all the measurements.

#### **CBCT Measurements**

The teeth were numbered and randomly divided to be scanned 4 teeth at a time. For length measurement CBCT scans, each tooth was placed in a prepared, empty mandibular premolar socket of the dry mandible (16). The mandible was fixed at the base of a plastic container filled with water to simulate soft tissue (25) and scanned by means of a CBCT scanner (Scanora 3D) at 90 kV, 13 mA, FOV of  $60 \times 60$  mm, and 0.133-mm<sup>3</sup> voxel size.

All CBCT scans were analyzed by 1 experienced endodontist. The images were manipulated using a personal computer running Microsoft Windows XP Professional (Microsoft Corp, Redmond, WA) on a 22.5-inch flat-screen monitor (resolution =  $1920 \times 1200$  pixels).

In the first section, the images were analyzed using the CBCT OnDemand3D software. The selected tooth was vertically positioned and slightly rotated to obtain a single longitudinal slice that best represented the whole length of the canal in both the BL and MD views (19). A measuring line was traced from the occlusal reference (flattened buccal cusp) to the AF, centered in the canal, following any visible deviation (Fig. 1A-C). The average between the BL and MD measurements was recorded as the conventional CBCT length (CL).

After 2 weeks, the 3D Endo software was used in the same scans. The interface of this program presents 5 major steps. The first, "Diagnosis and Pathology," allows the traditional visualization of CBCT images and rendering (Fig. 2A). In the second step, "3D Tooth Anatomy," the tooth is individualized by using a crop tool to remove most of the surrounding tissues (Fig. 2B). Then, the operator can identify the "Canal System" (Fig. 2C) by selecting in the axial images the location of the orifice and AF of each canal followed by an automatic line that connects both landmarks. In the fourth step, "3D Canal

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**Figure 2.** The sequence for obtaining the WL using 3D Endo software. (*A*) Initial 3D rendering of the CBCT image and (*B*) the selection of the tooth using the crop tool. (*C*) A blue pin is used to locate the axial images of both (*top*) the orifice and (*bottom*) the apical foramen, which are then automatically connected by a line. (*D*) The trajectory was adjusted following the curvatures of the root canal in both the BL and MD views (D). (*E*) The 3D canal pathway can be visualized by changing the transparency of the rendered model. (*F*) The occlusal view showing the virtual 15 K-file inserted in the canal trajectory; the *black circle* indicates (*G left*) the virtual location for the access that can be repositioned by using the *green* and *yellow arrows*, resulting in (*G rigbt*) the proper coronal angulation of the file. The *blue arrows* in *F* and *G* allow the apical positioning of the file, which was set at 0.0 mm from the foramen. (*H*) The final trajectory, from the center of the access to the foramen. The BL and MD views for (*I*) suggested length (3D-SL) and (*J*) operator-adjusted length (3D-OL).

Anatomy," the operator may use any of the anatomic planes to create midpoints and drag the line to be positioned into the center of the canal, resulting in a trajectory that follows the 3D curvatures of the root canal (Fig. 2D and E). Finally, in the fifth step, "Treatment Plan," after the software automatically inserts a virtual K-file into the canal trajectory, the apical position is set to AF. In our study, the coronal angulation of the file was positioned according to the concept of a straight-line endodontic access (Fig. 2F and G). After clicking the Suggest button, the suggested length (3D-SL) was calculated (Fig. 2I). This length was recorded, and then the virtual rubber stopper was manually adjusted to the coronal reference (Fig. 2J). The new length of the virtual file calculated by the software was recorded as the operator-adjusted working length (3D-OL). After 30 days, all the CBCT measurements were repeated to check the intraexaminer reliability.

#### **Actual Measurements**

The teeth were removed from the mandibles, cleaned with saline, and placed in recoded containers to keep the operator blinded to the CBCT measurements. The teeth were accessed, and the cervical third of the root canals was preflared (SX rotary file, Dentsply Sirona) using 2.5% sodium hypochlorite as the irrigating solution, which was delivered using a 30-G side-vented needle (NaviTip; Ultradent Products, South Jordan, UT). A manual size 15 file (C-Pilot; VDW, Munich, Germany) was used to remove pulp tissue and verify patency. The apical third of the roots were visualized under  $10 \times$  magnification (DF Vasconcellos), and the 15 K-file was introduced into the root canal until the tip became visible at the most coronal border of the AF opening (5, 13). Then, the rubber stop was carefully adjusted to the reference point (flattened buccal cusp). The distance between the file tip and the rubber stop was measured by using a digital caliper (DC) to 0.01-mm precision and recorded as the actual root canal length (AL). This measurement (AL) served as the gold standard for the other measurements obtained in this study.

#### **Electronic Measurements**

The electronic measurements were obtained using a mounting model as previously described (5, 26). Briefly, the teeth were embedded in freshly mixed alginate, and the canals were irrigated with 2.5% sodium hypochlorite. A 15 K-file connected to a DC with 0.01-mm precision was positioned at the coronal reference (flattened buccal cusp), and the DC was set to 0. The file was then inserted into the root canal, and the Root ZX EAL was connected to the system by placing the lip clip in the alginate and the file holder on the 15 K-file. The file was advanced until the flashing APEX mark remained stable for 5 seconds. The distance traveled by the file inside the canal, as shown by the DC, was recorded as the electronic length (EL).

#### **Statistical Analysis**

Data obtained from all measurements were statistically analyzed with the significance set at .05. The analysis of variance test was used to compare the absolute values. The Pearson correlation coefficient and 95% confidence intervals were calculated to compare the measurement methods. Dahlberg's formula and the *t* test were used to check the intraexaminer reliability for all the CBCT measurements. The difference between the measurements obtained by the different methods and the AL was assigned as negative and positive for lower and higher lengths, respectively. The proportion and percentages of

**TABLE 1.** Descriptive for the Mean Lengths Obtained Using the Different

 Measuring Methods

|       | n  | Mean  | SD   | Minimum | Maximum |
|-------|----|-------|------|---------|---------|
| AL    | 30 | 21.22 | 2.08 | 18.20   | 26.80   |
| 3D-SL | 30 | 21.09 | 2.07 | 18.25   | 26.80   |
| 3D-OL | 30 | 20.96 | 2.06 | 18.15   | 26.60   |
| CL    | 30 | 20.97 | 2.05 | 17.82   | 26.43   |
| EL    | 30 | 21.43 | 2.12 | 18.00   | 27.00   |

AL, actual length; 3D-SL, 3D Endo suggested length; 3D-OL, 3D Endo operator-adjusted length; CL, conventional cone-beam computed tomographic length; EL, electronic length.

the distribution of the differences were analyzed using the chi-square and proportion z tests.

#### Results

Table 1 presents the mean and standard deviation for the length measurements. The Levene test confirmed the assumption of homogeneity (P > .05). The 1-way analysis of variance test showed no difference among the groups regarding the mean length (P > .05). This was confirmed by the Pearson correlation (r > 0.975). The variance error of 3D-SL and 3D-OL measurements was 0.253% (Dahlberg's formula), and the high reliability was confirmed when comparing the mean measurements obtained after 30 days (t test, P > .05).

Table 2 shows the percentage distributions of the difference between the measurements obtained by the different methods compared with the respective visual length (AL). The measurements within  $\pm 0.5$  mm of the AF were considered acceptable. The chi-square test showed a significant difference in the distribution of the different methods (P < .05). The EL presented no measurements <0.5 mm for the AF, which was significantly different from the 3D-OL and CL (P < .05). The 3D-OL and 3D-SL presented significantly fewer cases in the range from 0.5–1 mm beyond the AF.

#### Discussion

The use of preoperative periapical radiographs to obtain the estimated endodontic length up to the radiographic apex is a routine clinical practice. However, the AF does not usually coincide with the radiographic apex (2-5). CBCT imaging has proven to be more accurate than periapical radiographs for preoperative WL length estimation (7, 16) and offers the advantage of assessing the anatomy of the canal in 3 dimensions. Because the AC can only be detected in histologic cuts or by using high-resolution micro–computed tomographic imaging (2, 5), the WL obtained in CBCT scans should consider the AF as a reference (19, 23).

3D Endo is a software developed for specific planning of endodontic procedures that can potentially be used with any set of CBCT scans (22). It presents a logical workflow that guides the operator

and allows the use of color codes for each canal to identify the canal trajectory in 3 dimensions (23). To the best of our knowledge, this is the first investigation of the use of this software for preoperative WL estimation using CBCT images. Thus, this study was designed to evaluate the accuracy and reliability of the 2 measuring options available in the 3D Endo interface (suggested and operator-adjusted) but also to establish a comparison with other methods, including conventional CBCT software (OnDemand3D) and the use of an EAL. The use of an ex vivo model was chosen because it allows the use of the actual length of the canal as the gold standard (13) and control of some of the clinical variables such as artifacts that might occur from position and motion of the patient, beam hardening from other materials, or noise from other anatomic structures (10, 16, 25). It should be noted that the results obtained in a laboratory setting should not be directly extrapolated to a clinical situation but rather used as a reference to understand the advantages and limitations of new technologies.

In this study, the FOV and voxel sizes allowed visualization of the entire mandible, mimicking a diagnostic CBCT scan that could have been taken for any other purpose. For endodontic evaluation, a smaller FOV and voxel size are preferable, aiming to reduce the radiation, obtain a higher spatial resolution, and improve the accuracy of the measurements (8, 10, 21, 27). However, the geometric analysis of the root canal system and WL determination have been reported to be reliable up to a voxel size of 0.2 mm<sup>3</sup> (10, 16). Accordingly, the present results showed a high correlation between all the CBCT measurements and the actual canal length.

In the literature, the root canal measurements obtained from CBCT imaging tend to be shorter than the actual lengths, ranging from -0.02 to -0.59 mm (11, 13, 14, 19, 21). A previous investigation (11) showed that the underestimation of CBCT measurements compared with histologic cuts varied depending on the segmentation procedures and acquisition settings. The present results for the mean lengths were within the reported ranges (ie, -0.25 mm for the CL, -0.13 mm for the 3D-SL, and -0.26 mm for the 3D-OL). Regarding the percentage of measurements shorter than -0.5 mm from the AF, 10% was found for 3D-SL and 20% for both 3D-OL and CL in the present study, whereas the reported range varies from 17%-50% (13, 19, 21). The discrepancies among the studies might be correlated to the different CBCT systems and the diverse exposure parameters (11, 21, 24, 28).

The accuracy of the CBCT measurements seems also to be related to the methods and the software's capabilities (11, 16). Following previous studies, when using the conventional OnDemand3D software (Fig. 1), the CL was obtained in a plane showing the coronal reference and the AF simultaneously (17, 18, 20, 21). These measurements depend highly on the operators' skills while selecting the view that can represent the entire length of the canal while identifying these landmarks (16, 24). In this sense, the semiautomated trajectory of the 3D Endo software can be suggested to improve the repeatability of these measurements (23). However, results showed that a high repeatability was observed regardless of the software. Possible

**TABLE 2.** Distribution and Percentage of the Different Measurement Methods

| 0                    |                         |                        |                        |                        |
|----------------------|-------------------------|------------------------|------------------------|------------------------|
|                      | 3D-SL                   | 3D-OL                  | CL                     | EL                     |
| Distance to AL in mm | n (%)                   | n (%)                  | n (%)                  | n (%)                  |
| -1.5 to -1.01        | 2 (6.7) <sup>a</sup>    | 2 (6.7) <sup>a</sup>   | 1 (3.3) <sup>a</sup>   | 0 (0.0) <sup>a</sup>   |
| –1 to –0.51          | 1 (3.3) <sup>abc</sup>  | 4 (13.3) <sup>b</sup>  | 5 (16.7) <sup>ab</sup> | 0 (0.0) <sup>c</sup>   |
| -0.5 to 0.00         | 19 (63.3) <sup>a</sup>  | 20 (66.7) <sup>a</sup> | 19 (63.3) <sup>a</sup> | 13 (43.3) <sup>a</sup> |
| 0.01–0.5             | 7 (23.3) <sup>abc</sup> | 4 (13.3) <sup>b</sup>  | 3 (10.0) <sup>ab</sup> | 11 (36.7) <sup>c</sup> |
| 0.51–1               | 1 (3.3) <sup>a</sup>    | 0 (0.0) <sup>a</sup>   | 2 (6.7) <sup>ab</sup>  | 6 (20.0) <sup>b</sup>  |

AL, actual length; 3D-SL, 3D Endo suggested length, 3D-OL, 3D Endo operator-adjusted length; CL, conventional cone-beam computed tomographic length; EL, electronic length. A negative value indicates position short (or coronal) to the actual root canal length. Different lowercase superscript letter indicates statistical significance within rows (P < .05).

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limitations of our investigation were the standardization of samples and the expertise of the operator; however, the use of straight roots with the axial foramen and flattened cusp probably reduced the measurement error. Future research should evaluate WL determination in multiple-rooted teeth and curved canals and the results from different levels of operators' experience.

Most of the previously described methods for measuring the root canals in CBCT images use a quantitative line following the canal pathway, from the AF up to the coronal reference, without considering the location of the access (13-15, 21). This method was used in the present investigation for the CL (Fig. 1B and C). On the other hand, 3D-Endo software allows the operator to locate the endodontic access virtually, and then the length is measured by using a virtual file whose trajectory complies with the canal pathway and the determined access position (Fig. 2H). This feature is likely to increase the accuracy of the WL because in a real situation the location of the access potentially changes the angulation of the file and its relation to the coronal reference. This might be correlated with the higher percentage of acceptable measurements of 3D Endo, 86% and 80%, respectively, for 3D-SL and 3D-OL followed by the CL at 73.3%. Although the present results showed no statistical difference between the 2 software programs (P > .05), they were above the percentages reported in the literature, ranging from 46%–70% (13, 19, 21) of WL measurements of  $\pm 0.5$  mm within the AF.

Following previous investigations (14, 21), the CL was the arithmetic mean between the BL and MD lengths (Fig. 1B and C), which is likely to increase the accuracy because it also considers the MD aspect of the canal anatomy (15, 23). However, even using both views, this approach is measuring the canal in two 2-dimensional projections of the CBCT scan. A morphologic analysis of the temporomandibular joint position (29) showed that the measurements performed in 3D spatial models were more accurate than using linear distances in the 2-dimensional slices of CBCT images. Similarly, in 3D Endo software, the final trajectory is a 3D rendering; the operator can perform adjustments to position the line centered in the canal according to any view (Fig. 2D). This segmented line can then be visualized by changing the transparency of the virtual model of the tooth (Fig. 2E). The present results (Table 1) showed that among the CBCT measurements, the 3D-SL was the most accurate but was not statistically different (P > .05). Further research should evaluate the influence of using this 3D root canal measurement in curved canals.

For WL measurements in 3D Endo, the operator can adjust both the apical distance (Fig. 2*F* and *G*) and the position of the coronal reference (22). In the present study, the 0.0-mm apical distance was selected for both 3D Endo WL functions because the gold standard was the actual length up to the AF. Therefore, the main difference between 3D-SL and 3D-OL was adjusting the position of the virtual rubber stopper to the coronal reference. The results showed that adjustments performed by the operator (3D-OL) reduced the automatic length (3D-SL) from 0 mm up to 0.2 mm, which might be considered clinically irrelevant (5, 21, 26, 30–32). Although there was no statistical difference, 3D-OL resulted in fewer cases beyond the AF. Therefore, it seems appropriate that when using 3D Endo software, the clinician should adjust or confirm the position of the virtual rubber stopper according to its preferred coronal reference.

Previous clinical studies have found that the WL measurement obtained in the CBCT images was similar to the EAL (14, 17, 18), whereas *in vitro* evaluations that used the actual length of the tooth as the gold standard have found that the EAL was more accurate than CBCT imaging (16, 19). Differences among studies can be correlated with the study design, type of teeth, anatomic landmarks, and different devices (14, 17, 19, 32). In the present study, the Root ZX was chosen because of its well-documented accuracy and repeatability

(4, 6, 14, 30-35), and the AF was used as a reference because it is a constant landmark (5, 26, 30-33) that can be located in the CBCT scans (9, 23).

The use of an EAL did not result in measurements shorter than 0.5 mm from the AF, which was significantly different from 3D-OL and CL. Because underestimation of the apical limit prevents proper disinfection of the canal (1, 2), the present results indicate that the preoperative CBCT lengths should always be clinically confirmed with an EAL (14, 16, 19). On the other hand, the EL resulted in more overextended measurements in the range of 0.5–1 mm beyond the AF (P < .05). This is explained by the selection of the APEX mark, which locates the AF with high precision but requires withdrawal of about 0.5–1 mm to establish a proper apical limit (5, 30–32).

For the cases in which a previous CBCT scan is already available, the present results support its use for preoperative WL estimation (13-15, 20, 21). Both functions for WL determination by 3D Endo were reliable and similar to conventional CBCT software. Nevertheless, the use of an EAL is required to confirm and adjust the apical limit because the WL is subjected to small changes during endodontic procedures (3, 34, 35).

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