UNIVERSIDADE FEDERAL FLUMINENSE

FACULDADE DE ODONTOLOGIA

ACURÁCIA E REPRODUTIBILIDADE DE MEDIDAS DENTÁRIAS EM MODELOS DIGITAIS TOMOGRÁFICOS: UMA REVISÃO SISTEMÁTICA E META-ANÁLISE

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Dissertação apresentada à Faculdade de Odontologia da Universidade Federal Fluminense, como parte dos requisitos para obtenção do título de Mestre, pelo Programa de Pós-Graduação em Odontologia.

Área de Concentração: Ortodontia

Orientadora: Prof[a]. Dr[a]. Adriana de Alcantara Cury Saramago
Co-orientadora: Prof[a]. Dr[a]. Andrea Fonseca Jardim da Motta

Niterói
2016

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LISTA DE ABREVIATURAS

3D – Tridimensional*;*

TCFC – Tomografia Computadorizada de Feixe Cônico.

LISTA DE ABREVIATURAS (INGLÊS)

CBCT – *Cone Beam Computed Tomography*;

SIGLE – *System for Information on Grey Literature in Europe*;

3D – *Three dimensional;*

PAR – *Peer Assessement Rating*;

ABO – *American Board of Orthodontics*;

ICON – *Index of Complexity, Outcome, and Need*;

DICOM – *Digital Imaging and Communications in Medicine;*

PRISMA – *Prefered Reporting Itens for Systematic Reviews and Meta-Analyses;*

QUADAS – *Quality Assessment of Diagnostic Accuracy Studies checklist*;

CT – *Computed Tomography*;

ICC – *Intraclass Correlation Coefficient*.

RESUMO

Ferreira, JB. Acurácia e reprodutibilidade de medidas dentárias em modelos digitais tomográficos: uma revisão sistemática e meta-análise. Niterói: Universidade Federal Fluminense, Faculdade de Odontologia; 2016.

O objetivo desta revisão sistemática com meta-análise foi avaliar a acurácia e reprodutibilidade de medidas dentárias lineares obtidas a partir de modelos digitais de estudo gerados da tomografia computadorizada de feixe cônico comparadas com modelos de gesso. As bases de dados eletrônicas *Cochrane Library*; *Medline database* (via *PubMed*); *Scopus*; *BVS* (Lilacs e BBO); *Web of Science*; e *System for Information on Grey Literature in Europe* (*SIGLE*), foram pesquisadas para a identificação e seleção de artigos científicos entre 1998 e Fevereiro de 2016. Os critérios de inclusão foram: ensaios clínicos prospectivos ou retrospectivos em humanos; artigos de validação e/ou comparação entre modelo de estudo dentário obtido através da TCFC e os modelos de gesso; e artigos que utilizaram medições lineares dentárias como ferramenta de avaliação. A qualidade metodológica dos estudos foi realizada através do *Quality Assessement of Diagnostic Accuracy Studies checklist* (QUADAS-2). Uma meta-análise foi realizada para validação das medidas de apinhamento e largura dentária mesiodistal. A busca nas bases de dados identificou um total de 3160 artigos e 554 artigos duplicados foram excluídos. Após leitura de títulos e resumos foram selecionados 12 artigos. Foram incluídos cinco artigos que atendiam aos critérios de elegibilidade após a leitura na íntegra. A qualidade metodológica obtida através do QUADAS-2 foi de pobre a moderada para evidência científica. Modelos digitais obtidos da tomografia computadorizada de feixe cônico são acurados para apinhamento e largura mesiodistal na maxila e mandíbula. As diferenças foram clinicamente aceitáveis para todas as medidas dentárias lineares, exceto para perímetro do arco maxilar. Os modelos digitais são reprodutíveis para todas as medidas consideradas neste estudo.

Palavras-chave: ortodontia, tomografia computadorizada de feixe cônico, modelos dentários.

ABSTRACT

Ferreira, JB. Accuracy and reproducibility of dental measurements on tomographic digital models: A systematic review and meta-analysis. Niterói: Universidade Federal Fluminense, Faculdade de Odontologia; 2016.

The aim of this systematic review with meta-analysis was to assess the accuracy and reproducibility of dental measurements obtained from digital study models generated from cone beam computed tomography compared with those acquired from plaster models. Electronic databases Cochrane Library, Medline (via PubMed), Scopus, VHL, Web of Science, and System for Information on Grey Literature in Europe were screened to identify papers from 1998 until February 2016. The inclusion criteria were: prospective and retrospective clinical trials in humans; validation and/or comparison articles of dental study models obtained from CBCT and plaster models; as well as articles that used dental linear measurements as an assessment tool. The methodological quality of the studies was assessed by using QUADAS-2 tool. A meta-analysis was performed to validate measurements of crowding and mesiodistal tooth width. The databases search identified a total of 3160 items and 554 duplicates were excluded. After reading titles and abstracts 12 articles were selected. Five articles were included after reading articles in full. The methodological quality obtained through QUADAS-2 was poor to moderate for scientific evidence. Digital models obtained from CBCT are accurate for maxillary and mandibular crowding and mesiodistal width. The differences were clinically acceptable for all dental linear measurements, except for maxillary arch perimeter. Digital models are reproducible for all measures considered in this study.

Key words: orthodontics, cone beam computed tomography, dental models.

SUMÁRIO

1. INTRODUÇÃO

Os consagrados modelos de estudo de gesso são essenciais para a realização de análises dentárias em Ortodontia. Características como tamanho de dentes, sobressaliência, sobremordida, apinhamento, análise de discrepância de arcos e análise de discrepância de Bolton são fundamentais para o diagnóstico, planejamento e obtenção do sucesso do tratamento.[1-7] Além disto, são relevantes para uso didático, servem como documentação para a pesquisa ortodôntica[8] e representam documento legal.[9]

O procedimento de medição realizado com paquímetro digital nos modelos de gesso é considerado padrão ouro ou padrão de referência em pesquisas ortodônticas.[1,3,6,8,10-14] O fato de servirem como base para a confecção de diversos aparelhos ortodônticos removíveis comprova a fidedignidade anatômica destes modelos.[15,16] Eles também apresentam vantagens como facilidade e baixo custo de confecção.[17]

Com o avanço tecnológico, modelos dentários estão também disponíveis em formato digital, o que afeta a clínica ortodôntica,[13] pela tendência atual em substituir os modelos de gesso por modelos digitais tridimensionais (3D).[8,18]

Desde a introdução dos modelos digitais em 1990,[19] pesquisas são amplamente realizadas para investigar modelos adquiridos por escaneamento a laser,[6,13,14,20,21] escaneamento holográfico,[22,23] estereofotogrametria,[24] escaneamento intraoral,[2,25] e mais recentemente, por tomografia computadorizada de feixe cônico (TCFC).[3,5,18,25-37]

A utilização desses diversos tipos de modelos tem sido mais frequente, em decorrência das vantagens em relação aos modelos de gesso. Não estão suscetíveis aos danos físicos ou degradação; o arquivo digital facilita a comunicação e transferência de arquivos entre profissionais, assim como a comunicação com o paciente; e elimina a necessidade e o custo de espaço físico para armazená-los.[12,15,19,24,38] Além disto, já é possível realizar *set ups* virtuais para simular resultados do tratamento ortodôntico;[38-42] aplicar os testes de medidas ordinais qualitativas, como os índices ou escalas ortodônticos (*Peer Assessement Rating* [*PAR*]; *American Board of Orthodontics* [*ABO*] *Obejctive Grading System*; *Index of Complexity, Outcome, and Need* [*ICON*]; and *Little's Index*) incorporados ao planejamento ou ao resultado do tratamento ortodôntico[17,19,29,38] e sobrepor imagens para acompanhar a evolução do tratamento.[43] Imagens digitais de TCFC acrescentam também informações dos níveis ósseos, das posições radiculares e da condição da articulação temporomandibular.[44] Porém ainda é discutível se a utilização de softwares para realizar medições e cálculos facilita e agiliza o processo.[3,45] Além disso, dependem de tecnologia com alto custo, que se encontra em rápida evolução; e ainda apresentam limitações relacionadas à segurança e privacidade,[45] além da chance de perda da informação arquivada eletronicamente.[46]

Não há consenso entre revisões sistemáticas sobre quais tipos de modelos digitais seriam mais aplicáveis na ortodontia. Duas revisões avaliaram a validade dos modelos digitais[15,38] e outras duas avaliaram validade e confiabilidade destes modelos.[19,21] Inúmeros tipos de aquisição de modelos digitais foram estudados nas revisões sistemáticas já existentes e apenas uma revisão individualizou o tipo de aquisição de modelo digital avaliado.[21] Estudos com medidas realizadas em modelos digitais gerados através da TCFC foram incluídos em duas revisões, no entanto não houve padronização em relação à forma de obtenção destes modelos através da tomografia e com quais tipos de modelos eram comparados. Estas divergências dificultam a obtenção de um resultado claro em relação à acurácia e reprodutibilidade destes modelos.

Com a evolução tecnológica e o aumento do uso de TCFC em Ortodontia, a obtenção de modelos digitais a partir deste exame se tornou possível, através da conversão dos arquivos *DICOM* (*Digital Imaging and Communications in Medicine*) para modelos digitais das arcadas dentárias, por um software de renderização de volume,[3,27,44] evitando a aquisição de impressões em alginato e eliminando as desvantagens deste procedimento.[27,29,44] Deste modo, muitos estudos estão sendo realizados com estes modelos digitais.[1,3,18,26,28,31-36,47-49] No entanto não foi encontrada revisão sistemática que analisou a acurácia e reprodutibilidade de medidas dentárias lineares realizadas nos modelos dentários gerados da TCFC em comparação aos modelos de gesso. Talvez as distorções oclusais nestes modelos e as limitações relacionadas aos indivíduos que serão submetidos a este exame sejam os motivos,[1,3] porém a constante evolução tecnológica torna iminente o seu aperfeiçoamento e a possibilidade de reunir todos os registros de diagnóstico a partir de um único método.[44]

Os termos acurácia e reprodutibilidade são considerados nesta revisão sistemática para avaliação das medidas. Acurácia ou validade referem-se à concordância entre os valores obtidos no teste avaliado em relação à medida real. Reprodutibilidade se refere à precisão de medições sucessivas em um mesmo teste.[50,51]

O objetivo desta revisão sistemática com meta-análise foi avaliar a acurácia e reprodutibilidade de medidas dentárias lineares obtidas de modelos de estudo digitais gerados a partir da tomografia computadorizada de feixe cônico comparadas com as medidas em modelos de gesso. Considerando-se que os métodos sejam acurados e reprodutíveis pretende-se indicar a análise de medidas dentárias a partir da TCFC para pacientes que já possuam este exame.

2. METODOLOGIA

A elaboração desta revisão sistemática foi baseada nas orientações e diretrizes do *Prefered Reporting Itens for Systematic Reviews and Meta-Analyses: The PRISMA Statement.*[52] O protocolo foi registrado na base de dados da PROSPERO por meio do número CRD42015029859 (http://www.crd.york.ac.uk/PROSPERO).

Com o intuito de selecionar as palavras-chave para a busca eletrônica e aplicar os critérios de seleção, a pergunta desta revisão foi elaborada no formato PECO (Tabela 1).

Tabela 1. PECO

P- Participante / População	Pacientes ortodônticos que tenham TCFC
E- Exposição	TCFC realizada para planejamento do tratamento ortodôntico
C- Comparação	Entre medidas lineares dentárias em modelo de estudo digital obtido da TCFC e modelo de gesso do mesmo indivíduo
O- "*Outcome*" – Resultados Esperados	Avaliação de acurácia e reprodutibilidade de medidas lineares dentárias em modelo de estudo digital obtido da TCFC
Pergunta	As medidas lineares dentárias obtidas do modelo de estudo digital, gerado a partir da TCFC, são acuradas e reprodutíveis quando comparadas com as mesmas medidas obtidas do modelo de gesso?
Hipótese nula	As medidas obtidas nos dois métodos são acuradas e reprodutíveis

Os critérios para inclusão dos estudos elegíveis que respondem à pergunta do formato PECO foram: 1- ensaios clínicos transversais em humanos; 2- artigos de validação e/ou comparação entre o modelo de estudo dentário gerado através da TCFC do indivíduo e os modelos de gesso; 3- artigos que avaliaram acurácia e reprodutibilidade de medidas lineares dentárias entre o modelo de estudo dentário gerado através da TCFC do indivíduo e os modelo de gesso. Os critérios de exclusão foram: 1- estudos em animais; 2- estudos em vitro; 3-relatos de casos; 4-séries de casos; 5- artigos de revisão; 6- artigos de opinião; 7- editoriais; 8- livros; 9-artigos técnicos; e 10- medições realizadas em imagens diretas da TCFC, sem a obtenção do modelo de estudo dentário digital.

A pesquisa bibliográfica para identificação dos estudos foi realizada através de busca eletrônica nas seguintes bases de dados: *Medline database (via PubMed), Scopus* (via Portal Periódicos Capes)*, Web of Science* (via Portal Periódicos Capes)*, BVS (Lilacs e BBO), Cochrane Library,* e *System for Information on Grey Literature in Europe (SIGLE)*. As estratégias de busca para cada base foram elaboradas com o auxílio e orientação de uma bibliotecária (D.M.T.P.F.), utilizando palavras-chave e termos livres relacionados ao assunto da pesquisa, com o intuito de abranger o maior número de artigos relacionados à pergunta do formato PECO (Tabela 2).

Tabela 2. Estratégias de busca

Medline	(((((((((Orthodontics[MeSH Terms]) OR Odontometry[MeSH Terms]) OR "Dental Arch"[MeSH Terms]) OR Orthodontic[Title/Abstract]) OR Odontometry[Title/Abstract]) OR Skulls[Title/Abstract]) OR Teeth[Title/Abstract])) AND ((((("Cone-Beam Computed Tomography"[MeSH Terms]) OR "Imaging, Three-Dimensional"[MeSH Terms]) OR "Cone-Beam Computed Tomography"[Title/Abstract]) OR "Three-Dimensional Imaging"[Title/Abstract]) OR CBCT[Title/Abstract]) OR 3D[Title/Abstract])) AND ((((((((("Dental Models"[MeSH Terms]) OR "Image Processing, Computer-assisted"[MeSH Terms]) OR "Dental Models"[Title/Abstract]) OR "Dental Casts"[Title/Abstract]) OR "Digital Models"[Title/Abstract]) OR "Digital Model"[Title/Abstract]) OR "Study Models"[Title/Abstract]) OR "Virtual Models"[Title/Abstract]) OR "Plaster Models"[Title/Abstract])
Scopus	((TITLE-ABS-KEY (orthodontics OR odontometry OR "Dental Arch" OR orthodontic OR skulls OR teeth)) AND (TITLE-ABS-KEY ("Cone-Beam Computed Tomography" OR "Three-Dimensional Imaging" OR cbct OR 3d)) AND (TITLE-ABS-KEY ("Dental Models" OR "Dental Casts" OR "Digital Models" OR "Digital Model" OR "Study Models" OR "Virtual Models" OR "Plaster Models")))
Web of Science	#1) (Orthodontics OR Odontometry OR "Dental Arch" OR Orthodontic OR Skulls OR Teeth) #2) ("Cone-Beam Computed Tomography" OR "Three-Dimensional Imaging" OR CBCT OR 3D) #3) ("Dental Models" OR "Dental Casts" OR "Digital Models" OR "Digital Model" OR "Study Models" OR "Virtual Models" OR "Plaster Models") #4) #3 AND #2 AND #1

VHL	tw:((tw:((tw:((mh:(orthodontics OR ortodontia OR odontometry OR odontometria OR "Dental Arch" OR "Arco Dental")))) OR (tw:((tw:(orthodontics OR ortodontia OR odontometry OR odontometria OR "Dental Arch" OR "Arco Dental" OR orthodontic OR ortodôntico OR skulls OR crânios OR teeth OR dentes)))))) AND (tw:((mh:((mh:("Cone-Beam Computed Tomography" OR "Tomografia Computadorizada de Feixe Cônico" OR "Imaging, Three-Dimensional" OR "Imagem Tridimensional")))) OR (tw:((tw:("Cone-Beam Computed Tomography" OR "Tomografia Computadorizada de Feixe Cônico" OR "Three-Dimensional Imaging" OR "Imagem Tridimensional" OR cbct OR tcfc OR 3d)))))) AND (tw:((mh:((mh:("Dental Models" OR "Modelos Dentários" OR "Image Processing, Computer-assisted" OR "Processamento de Imagem Assistida por Computador")))) OR (tw:((tw:("Dental Models" OR "Modelos Dentários" OR "Dental Casts" OR "Modelos de Gesso" OR "Digital Models" OR "Modelos Digitais" OR "Digital Model" OR "Modelo Digital" OR "Study Models" OR "Modelos Estudo" OR "Virtual Models" OR "Modelos Virtuais" OR "Plaster Models" OR "Modelos de Gesso")))))))
Cochrane	#1 MeSH descriptor: [Orthodontics] explode all trees #2 Orthodontics #3 #1 or #2 #4 MeSH descriptor: [Odontometry] explode all trees #5 Odontometry #6 #4 or #5 #7 MeSH descriptor: [Dental Arch] explode all trees #8 "Dental Arch" #9 #7 or #8 #10 Skull #11 Teeth #12 #3 or #6 or #9 or #10 or #11 #13 MeSH descriptor: [Cone-Beam Computed Tomography] explode all trees #14 "Cone-Beam Computed Tomography" #15 #13 or #14 #16 MeSH descriptor: [Imaging, Three-Dimensional] explode all trees #17 "Imaging Three-Dimensional" #18 #16 or #17 #19 "Three-Dimensional Imaging" #20 CBCT #21 3D #22 #15 or #18 or #19 or #20 or #21 #23 MeSH descriptor: [Dental Models] explode all trees #24 "Dental Model" or "Dental Models" #25 #23 or #24 #26 MeSH descriptor: [Image Processing, Computer-Assisted] explode all trees #27 "Dental Casts" or "Dental Cast" #28 "Digital Models" or "Digital Model" #29 "Study Models" or "Study Model" #30 "Virtual Models" or "Virtual Model" #31 "Plaster Models" or "Plaster Model" #32 #25 or #26 or #27 or #28 or #29 or #30 or #31 #33 #12 and #22 and #32
SIGLE	orthodontics AND cone-beam computed tomography dental arch AND cone-beam computed tomography dental models AND cone-beam computed tomography

A busca sistemática foi realizada até fevereiro de 2016, sem restrição de idioma e com aplicação do filtro de data (01/01/1998 a 12/02/2016). O filtro foi aplicado em virtude do desenvolvimento da TCFC no ano de 1998.[53]

Após o resultado final da busca eletrônica foram eliminados os artigos em duplicata. Em seguida os títulos e resumos foram lidos independentemente por dois revisores (J.B.F. e D.S.A.) e os artigos que preencheram os critérios de inclusão foram selecionados para a leitura na íntegra. Quando o título e o resumo não forneceram informações suficientes para a elegibilidade, o trabalho também foi examinado na íntegra. Uma busca manual foi realizada nas referências dos artigos selecionados para identificar possíveis títulos relevantes não encontrados através da busca eletrônica. Os conflitos entre os dois revisores foram resolvidos por um terceiro revisor (A.A.C.S.) em reunião de consenso.

A qualificação metodológica dos estudos selecionados foi conduzida por dois revisores (J.B.F. e I.O.C.), através do *Quality Assessment of Diagnostic Accuracy Studies checklist* (QUADAS-2),[54,55] a partir do programa Review Manager (version 5.3, Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014), com o intuito de responder a pergunta clínica desta revisão.

O QUADAS-2 consta de dois principais tópicos para análise: “risco de viés” e “preocupação em relação à aplicabilidade”. A partir destes tópicos, são preenchidas questões relacionadas aos seguintes domínios: seleção dos pacientes, teste avaliado, padrão de referência, e fluxo e tempo.

O pesquisador tem a liberdade de acrescentar ou suprimir perguntas. A pergunta: “Foi utilizado um limiar pré-especificado?”, foi excluída do segundo domínio (teste avaliado), e outras cinco foram adicionadas ao mesmo domínio no intuito de extrair dados complementares para avaliação dos estudos. Cada estudo foi avaliado de acordo com as seguintes questões para: 1- Seleção dos pacientes 1a- Foi inscrita uma amostra consecutiva ou aleatória de pacientes? 1b- Foi evitado ensaio caso-controle? 1c- O estudo evitou exclusões inapropriadas? 2- Teste avaliado 2a- Os resultados do teste avaliado foram interpretados sem o conhecimento dos resultados do padrão de referência? 2b- O campo de visão foi descrito? 2c- O scanner da TCFC foi descrito? 2d- O tamanho do voxel foi descrito? 2e- O software de aquisição de modelo digital foi descrito? 2f- O software para medição de modelo digital foi descrito? 3- Padrão de referência 3a- O padrão de referência é capaz de classificar corretamente a condição de alvo? 3b- Os resultados do padrão de referência foram interpretados sem o conhecimento dos resultados do teste avaliado? 4- Fluxo e tempo 4a- Houve um intervalo apropriado entre o teste avaliado e o padrão de referência? 4b- Todos os pacientes receberam o mesmo padrão de referência? 4c- Todos os pacientes foram incluídos nas análises? (Anexo 1)

Foram atribuídos os scores '*yes*', '*no*' e '*unclear*' para cada questão do QUADAS-2. O risco de viés foi julgado baixo quando todas as questões de cada domínio tiveram score '*yes*' atribuído. Foi atribuído um potencial risco de viés quando qualquer questão recebeu score '*no*'. A categoria '*unclear*' foi usada quando foi fornecido dados insuficientes para permitir julgamento. Discordâncias entre os revisores nesta fase foram solucionadas através de reunião de consenso com um terceiro revisor (A.A.C.S.).

Foi estabelecido que valores maiores que 0,5 mm seriam clinicamente significativos para médias das diferenças das larguras mesiodistais dentárias e medidas transversas dos arcos; e maiores que 2,0 mm, para medidas obtidas através de somatórios.[7,56]

Os dados foram extraídos dos artigos selecionados e organizados em tabela, de acordo com os seguintes aspectos: autor e ano de publicação, tamanho da amostra, características dos participantes, teste avaliado, padrão de referência, número de examinadores, quantidade de repetição por examinador, medidas avaliadas e resultados.

A meta-análise foi realizada entre os estudos que validaram as medidas de apinhamento e da largura mesiodistal dentárias em diferentes grupos de dentes. A diferença média entre as medidas lineares do modelo obtido a partir do modelo de gesso foi subtraída das medidas da TCFC na maioria dos estudos (TCFC menos modelo de gesso). Os dados foram analisados no Comprehensive Meta-Analysis software (*version* 3.2.00089, USA) com *random effect model.* A heterogeneidade entre os estudos foi testada através do *Q-value,* I^2 *index* e *Tau*^{2}.

3. ARTIGO PRODUZIDO

Title: Accuracy and reproducibility of dental measurements on tomographic digital models: A systematic review and meta-analysis

Short title: Accuracy and reproducibility of dental measurements on digital models from TCFC

Keywords: orthodontics; cone beam computed tomography; dental models

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ABSTRACT

Objective: The aim of this systematic review with meta-analysis was to assess the accuracy and reproducibility of dental measurements obtained from digital study models generated from cone beam computed tomography (CBCT) compared with those acquired from plaster models. **Materials and Methods:** Electronic databases Cochrane Library, Medline (via PubMed), Scopus, VHL, Web of Science, and System for Information on Grey Literature in Europe (SIGLE) were screened to identify papers from 1998 until February 2016. The inclusion criteria were: prospective and retrospective clinical trials in humans; validation and/or comparison articles of dental study models obtained from CBCT and plaster models, as well as articles that used dental linear measurements as an assessment tool. The methodological quality of the studies was carried out by QUADAS-2 tool. A meta-analysis was performed to validate measurements of crowding and mesiodistal tooth width. **Results:** The databases search identified a total of 3160 items and 554 duplicates were excluded. After reading titles and abstracts 12 articles were selected. Five articles were included after reading in full. The methodological quality obtained through QUADAS-2 was poor to moderate. **Conclusions:** Digital models obtained from CBCT are accurate for maxillary and mandibular crowding and mesiodistal width. The differences were clinically acceptable for all dental linear measurements, except for maxillary arch perimeter. Digital models are reproducible for all measures considered in this study.

Key words: orthodontics, cone beam computed tomography, dental models.

INTRODUCTION

The traditional study plaster models are essential for performing dental analysis in Orthodontics. Characteristics such as tooth size, overjet, overbite, crowding, arch discrepancy and Bolton analysis are fundamental in diagnosis and successful treatment results.[1-7] Furthermore, they are relevant for educational use, serve as documentation for orthodontic research[8] and represent legal document.[9]

The measurement procedure with digital caliper in plaster models is considered the gold standard or reference standard in orthodontic research.[1,3,6,8,10-14] Those models may serve as a basis for making several removable orthodontic appliances and confirm this anatomical reliability.[15,16] They also have advantages such as easy and low cost production.[17]

Technological advancement has allowed the production of dental models in digital format, which affects the orthodontic clinics[13] by the current trend to replace the plaster models by three-dimensional digital models (3D).[8,18]

Since the introduction of digital models in 1990,[19] searches have been extensively performed to investigate models obtained by laser scanning,[6,13,14,20,21] holographic scanning,[22,23] stereophotogrammetry,[24] intra oral scanning,[2,25] and most recently, cone beam computed tomography (CBCT).[1,3,18,25-37]

The use of such different types of digital models has been increasing, due to advantages over plaster models. They are not susceptible to physical damage or degradation, the digital archive facilitates communication between professionals and with patients, and eliminates the need and cost of physical space to store them.[12,15,19,24,38] In addition, it is possible to perform virtual setups to simulate results of orthodontic treatment;[38-42,57] apply qualitative measures ordinal tests, as the indexes or orthodontic scales (Peer Assessement Rating [PAR]; American Board of Orthodontics [ABO] Objective Grading System; Index of Complexity, Outcome, and Need [ICON]; and Little's Index) embedded in the planning or the result of orthodontic treatment,[17,19,29,38] and superimpose images to follow-up progress, and Orthodontic treatment outcomes monitor the progress of treatments.[43] Digital images of CBCT also add information, such as bone levels, root positions and the condition of the temporomandibular joint.[44] However, it is still questionable whether the use of software to perform measurements and calculations facilitates and accelerate the process.[3,45]

Moreover, its acquisition depends on the technology with high cost, quickly evolving and has limitations relating to security and privacy, as well as the risk of loss of information electronically filed.

There is no consensus between systematic reviews on what types of digital models would be applicable in orthodontics. Two reviews evaluated the validity of digital models[15,38] and two assessed the validity and reliability of these models.[19,21] Numerous types of acquisition of digital models have been covered on the existing studies included on systematic reviews and only one revision individualized a type of acquisition of digital model to be evaluated.[21] Studies evaluating measurements on digital models generated by CBCT were included in two reviews,[19,21] however there was no standardization in relation to how to obtain these models through tomography and what types of models were compared. These differences make it difficult to obtain a clear result with regard to accuracy and reproducibility of digital models.

Considering the technological developments and increased use of CBCT in Orthodontics, the production of digital models from the patient's CBCT scans was made possible,[3,27,44] avoiding the acquisition of impressions and eliminating the disadvantages of this procedure.[27,29,44] As a result of this technological progress, many studies have been conducted with digital models obtained from the patient's CBCT scan.[1,3,18,26,28,31-36,47-49] However, no systematic review aimed at analyzing the accuracy and reproducibility of linear dental measurements in these models compared to plaster models. Possibly, this fact occurs because of occlusal distortions in CBCT models, and limitations that are associated with which individuals are submitted to this examination. However, the constant technological evolution of CBCT maybe will make it a single diagnostic method.[44]

The terms accuracy and reproducibility are considered in this systematic review for the evaluation of measurements. Accuracy refers to the agreement between the values obtained on the index test and reference standard; and it can be replaced by the term validity. It refers to the term reproducibility the precision of successive measurements on the same test.[50,51]

The purpose of this systematic review and meta-analysis was to assess the accuracy and reproducibility of linear dental measurements on digital study models generated from CBCT compared with plaster models. If methods are accurate and reproducible, dental measurements analysis on digital models generated from CBCT for patients who already have this test diagnostic should be indicated.

MATERIALS AND METHODS

The elaboration of this systematic review was based on the guidelines and directives of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement.[52] The protocol was registered in the PROSPERO database under the number CRD42015029859 (http://www.crd.york.ac.uk/PROSPERO).

The selection of keywords for electronic search and the eligibility criteria were based on the following question: Are dental linear measurements of digital study model generated from CBCT scans accurate and reproducible compared to the same measurements on plaster models? (Table 1, page 33)

The criteria for inclusion of eligible studies were: 1- prospective and retrospective clinical trials in humans; 2- validation and/or comparison articles of dental study models generated from CBCT scans and plaster models; 3- articles that assessed accuracy and reproducibility of dental linear measurements between dental study models generated from patient's CBCT scan and plaster model. Exclusion criteria were: 1- animal studies; 2- in vitro studies; 3- case reports; 4- case series; 5- review articles; 6- opinion articles; 7- editorial; 8- books; 9- technical articles; and 10- measurements in direct images of CBCT without obtaining the digital dental study model.

The literature search to identify studies was conducted through electronic search in the following databases: Medline database (via PubMed), Scopus, Web of Science, VHL (Lilacs and BBO), Cochrane Library, and System for Information on Grey Literature in Europe (SIGLE). Search strategies for each base were prepared with the help and guidance of a librarian using keywords and free terms related to the subject of research, in order to reach the largest number of articles related to the review question. The search idiom was adapted for the different databases. There were no restrictions for language. The search strategy for Medline database is provided in Table 2 (page 33), and the systematic complete search strategy was conducted until February 2016, and application of the date filter (01/01/1998 to 02/12/2016). The filter was applied due to the development of CBCT in 1998.[53]

Duplicate articles were eliminated after the final result of the search. Then the titles and abstracts were read independently by two reviewers (J.B.F. and D.S.) and the articles that met the inclusion criteria were selected for reading in full. When the title and abstract did not provide sufficient information for eligibility, the research was also examined in full. A manual search was conducted in the references of the selected articles to identify possible relevant titles not found by electronic search. Disagreements between the two reviewers were resolved by a third reviewer (A.A.C.S.) in consensus meeting.

The methodological quality of the selected studies was evaluated by two reviewers (J.B.F. and I.O.C), through the Quality Assessment of Diagnostic Accuracy Studies checklist (QUADAS 2),[54,55] using the Review Manager software (version 5.3, Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014).

QUADAS-2 consists of two main topics for analysis: "bias risk" and "concern about the applicability". From these topics, the following domains are filled for each study: patient selection, index test, reference standard, and flow and timing.

The evaluator can formulate new questions or remove existing questions. Then, the question ‘If a threshold was used, was it prespecified?’ was excluded from the second domain (index test), and five others questions were added to the same domain in order to extract additional data for the assessment of studies: Was field of view described?; Was CBCT scanner described?; Was voxel size described?; Was type of software for models acquisition described?; Was type of software for models measurements described? (*Anexo* 1, page 48).

Each studies was assigned 'yes', 'no' and 'unclear' for each question. The risk of bias was judged low when all questions of each domain had score 'yes' assigned. A potential risk of bias was assigned when any question received score 'no'. The ‘unclear’ category was used when it was provided insufficient data to allow trial. Disagreements between reviewers at this stage were resolved by consensus meeting with a third reviewer (A.A.C.S.).

In this systematic review, we set that values greater than 0.5 mm, would be clinically significant for mean differences of mesiodistal tooth width, and transversal widths; and greater than 2.0 mm to sums of measurements.[7,56]

Data were extracted from selected articles, and organized in tables, according to the following aspects: author and year of publication, sample size, characteristics of participants, index test, reference standard, numbers of examiners, readings per examiner, measurements and findings.

The meta-analysis was performed gathering studies which validated the measurements of crowding in dental arch and the mesiodistal tooth width in different groups. The mean difference was presented subtracting the measurements of plaster models from the measurements in models generated from CBCT, in the majority of studies,[1,3,18,31] except in one article.[32] The data were assessed in the Comprehensive Meta-Analysis software (version 3.2.00089, USA) with the random effect model and the heterogeneity among studies was tested trough the Q-value, I^2 index e Tau^2.

RESULTS

Study Selection

The search of all databases provided a total of 3160 studies. The duplicates were removed and 2606 titles and abstracts were read, 12 included studies met the eligibility criteria, and were related to the subject. After full text reading, 7 were excluded for the following reasons: 1- not used linear measurements;[58] 2- digital model generated from axial CT scan;[59] 3- measurements in images of CBCT without obtaining the digital dental study model.[5,60-63] A flow diagram describing the selection process and the results is illustrated in Figure 1 (page 34). One[3] eligible article was not included in the meta-analysis for not presenting enough data (mean, standard deviation, mean difference, p-value) for comparison. No article was found in the manual search. In order to clarify doubts about the digital model generation, the authors were contacted[60,63] with no success. No article was eliminated after QUADAS-2 tool application.

Study Characteristcs

The selected studies were conducted in Korea,[31] China,[32] United States,[1,3] and Canada.[18] Three studies were published in English,[1,3,18] one was published in Korean and the last one in Chinese.[31,32]

We found 5 comparative articles as a result of the systematic literature search and eligibility criteria.[1,3,18,31,32] All of them included dental linear measurements to comparison through the investigated methods, samples of dental plaster models and models generated from direct patient's CBCT scans.

The sample size ranged from 20 upper models to 30 sets of models. All selected studies presented a sample of orthodontic patients with permanent dentition. One study[32] included patients with crowding up to 5 mm and others two studies[1,31] excluded dentition with metal restorations that damaged the image quality. All studies obtained CBCT scans with a voxel size of 0.3 mm^3. [31,3,18,31,32]

From the selected studies, all five assessed the accuracy and intraexaminer reproducibility;[1,3,18,31,32] and three evaluated the interexaminer reproducibility [1,3,18] of linear measurements taken on digital models generated from CBCT scan. Four digital model systems were assessed in the studies: Accurex,[31] Mimics,[32] Rapidiform,[1] and Anatomodels.[3,18] All measurements taken on digital models were compared with those obtained on plaster models. The number of examiners that performed the measurements ranged between one to five and the number of times of repeated readings were not uniform between the studies. The data extracted from individual studies was presented in Table 3 (page 41).

Risk of Bias of included studies

According to QUADAS-2, the risk of bias of selected studies is low to moderate. The domains that may introduce bias were patient selection, index test, and reference standard (Figure 2, and 3, page 35). No concern regarding applicability was detected in all studies included. The lack of description of sample randomization[1,31,32] and blinding[1,18,31,32] were the main sources of bias. Likewise, the field of view[18] and appropriate interval between the methods[32] were not described in specific studies (*Anexo* 1, page 48).

Synthesis of Results

Results of the selected studies included accuracy, (*Anexo* 3, page 52) intraexaminer (*Anexo 4*, page 55), and interexaminer reproducibility (*Anexo 5*, page 59) of linear measurements on digital models generated from CBCT when compared with plaster models. Included studies selected the following linear measurements: mesiodistal tooth width, intercanine width, interpremolar width, intermolar width, sum of anterior teeth, sum of all teeth, required space, available space / arch perimeter, arch crowding, arch length, arch length discrepancy.

Accuracy

The measurements selected to evaluate accuracy were organized into four groups: arch length and crowding, tooth width, arch width, and Bolton discrepancy.

Arch length and crowding

Four studies assessed the accuracy of measurements associated to space analysis and crowding between digital models generated from CBCT and plaster models.[1,18,31,32] The differences between measurements of crowding ranged from 1.06 mm[18,32] to 1.75 mm.[18] Luu et al.,[18] showed a high discrepancy for maxillary perimeter measurement of 3.38 mm. Two authors[1,18] used ICCs (intraclass correlation coefficient) when compared arch length obtained from plaster models and digital model generated from CBCT, and found a correlation that ranged from poor to excellent between the methods. The poor correlation was identified for maxillary perimeter measurement.[18]

The study of Lv et al.[32] was excluded from the meta-analysis for not presenting the discrepancy in the lower arch. When considering the three studies compared, there was not a significant difference ($p>0.05$) in the maxillary and mandibular arch, and the examiners tended to overestimate the digital models generated from CBCT crowding compared to plaster models, except in Lim and Lim mandibular arch (Figure 4, page 36). The heterogeneity among the studies in maxillary arch ($I2=0$) was considerably lower than in mandibular arch ($I2=76\%$).

Tooth width

Differences in tooth width between digital model obtained from CBCT and plaster model were measured in three studies.[18,31,32] The mean difference ranged from 0.01 mm, measured at lower lateral incisor[31] to 0.47 mm, measured at upper central incisor.[18] Most tooth width measurements in digital model obtained from CBCT were lower than plaster model, according to the results reported by Lim and Lim,[31] and Lv et al.,[32] and were higher on the results of Luu et al.[18] The ICC calculated by Luu et al. verified a correlation that ranged from poor to good in the majority of measurements. Tooth width was evaluated by Grunheid et al.[3] through

Bland Altman analysis and found a bias of 0.191 mm with limit of agreement interval width of 1.521 and a mean squared error of 0.181 mm.

In the meta-analysis, the data from the study of Lim and Lim was duplicated to each hemi-arch (right and left sides). In the table of the study of Lv et al.,[32] the author presented the mean difference subtracting the measurements of digital models generated from CBCT from measurements in plaster models and the values were converted to be compared, this study only evaluated datas from maxillary. The teeth measurements were assessed in separeted groups : incisors, canines, premolars and molars. There were no significant difference ($p>0.05$) in all groups. The heterogeneity was high ($I2= 64$ to 93), except in some subgroups in mandibular arch (32, 42, 33, 43, 34, 44, 36 with $I2=0$) and the underestimation and overestimation of the teeth measuments varied in the studies. (Figure 5 to 8, page 37 to 40).

Arch width

Transverse dimensions were measured in three studies.[18,31,32] Mean differences ranged from 0.01 mm,[31] to 0.39 mm,[18] both measured at mandibular first molar.[18,31] Statistically significant differences were found on mandibular intermolar width,[18] and maxillary intercanine width in individual studies.[31] Luu et al. identified an excellent correlation by ICC.

Bolton analysis discrepancy

Regarding Bolton ratio, differences were compared between methods on two studies.[18,31] The mean differences ranged from -0.35 mm, measured at anterior Bolton ratio,[31] to -1.95 mm, measured at overall Bolton ratio.[18] Statistically significance difference was observed for anterior[18] and overall Bolton ratio in individual studies.[18,31] A poor correlation was verified by Luu et al. when calculated ICC. Lim and Lim,[31] applied Pearson correlation and verified a correlation of 0.764 for anterior Bolton analysis discrepancy and 0.718 for overall Bolton ratio between digital models generated from CBCT and plaster models.

Intraexaminer reproducibility

All included studies assessed intraexaminer reproducibility of linear measurements on digital models generated from CBCT.[1,3,18,31,32] The results of Lim and Lim,[31] showed statistically significant differences in mesiodistal width of lower lateral incisor and lower 2nd premolar when the paired t-test was applied. The absolute mean difference showed that differences of same measurements on digital models obtained from CBCT were higher in 19 measurements and were smaller in 9 measurements..[31] ICCs parameters were verified on three studies.[1,18,32] A good correlation was demonstrated by Lv et al.,[32] and an excellent correlation was demonstrated by Akyalcin et al.,[1] and Luu et al.[18] The results of tooth width reported by Grunheid et al.,[3] showed bias of 0.006 mm, limit of agreement interval width of 0.987 mm, and mean squared error of 0.063 mm.

Interexaminer reproducibility

The interexaminer reproducibility was reported on three studies.[1,3,18] Akyalcin et al.,[1] found with ICC analysis an excellent correlation of linear measurements on digital models generated from CBCT, whereas the correlation recorded by Luu et al.,[18] was mostly good and excellent. Interobserver reproducibility was verified by Luu et al,[18] through ANOVA tests, a statistically significant difference was observed for upper right canine, upper 2nd premolar, lower left lateral incisor, lower right central incisor, upper intermolar width, lower intercanine width and upper and lower perimeter and crowding. Bland Altman analysis was used by Grunheid et al.[3] to assess interobserver reproducibility of tooth witdth on digital model generated from CBCT, and it was found a bias that ranged from 0.035 mm to 0.912 mm, the limit of agreement interval width ranged from 1.330 mm to 2.408 mm, and the mean squared error ranged from 0.141 mm to 1.200 mm.

DISCUSSION

Modifying what is traditional, reliable and valid requires the use of arguments obtained through numerous, extensive and qualified research.

Dental models have been reported to be an essential record of patient's occlusion and extremely used in the decision of treatment planning.[4,17] Although plaster models are currently considered the gold or reference standard for orthodontic diagnostic,[1,3,4,16-18,31,32,59] measurements in plaster models may involve errors,[3,18] and there are a few known reported.[1,12,15,19,24,38] Some random, and systematic errors in measurements on those models may be a result of the measuring instrument, difficulties in the measurement process, operator skill, and/or by alginate expansion because of imbibition of water.[18]

Nowadays there is a tendency to incorporate digital models into the orthodontic practice, but their potential advantages[12,15,19,24,38] would be rejected if the accuracy and reproducibility of their analysis methods were not comparable with those taken on plaster models with digital calipers.[3] Digital models generated from patient's mouth impressions might be associated with some errors like alginate shrinkage during transportation to companies that generate digital models,[13] and/or loss of information because of scanning process.[3] However, previous systematics reviews have concluded that digital models are accurate, reproducibly, and clinically acceptable for dental measurements.[15,19,21,38]

Although almost all digital models are made from alginate impressions, which are directly scanned or poured in plaster to obtain the study model and then scanned,[3] the digital models also could obtained from CBCT of the head of patient when the patients who already had a CBCT scan for other clinical reasons. Digital models generated from CBCT scans exhibit limited anatomic reproduction of the occlusal and interproximal tooth parts.[1,3] If the patient treatment requires this record, could the impression procedure be spared and could the professional avoid all the disadvantages related to plaster models? Likewise, they would benefit from all the advantages of digital models.

The methodological quality of the selected studies found gaps in few signaling questions, according to QUADAS-2 tool. Most studies have not clearly described about blinding of the investigators when the results of the tests were interpreted, and sample randomization.[1,31,32] No concerns about applicability of the methods used in the studies were identified, and all of them matched the review question. The lack of an information about appropriate interval between the acquisitions of plaster model and digital model, could cause a bias as a result of oral diseases or trauma which could change the morphology of the teeth that would be submitted to measurements.[32]

Regarding previous systematic reviews, only Rossini et al.,[19] selected an article[1] that was in common with our systematic review. This review[19] was the latest published in the literature, and conducted the search strategy until November 2014. The difference between the results of the included articles is probably due to different review questions, a search strategy that provided a large literature scan and the differences in our selection criteria. We choose to focus on quantitative linear measurements on digital models generated from direct patient's CBCT scans and compared solely with plaster models.

The accuracy of dental linear measurements obtained from digital models generated from CBCT compared with those obtained from plaster models showed clinically insignificant mean differences for almost all analyzed measurements. This agrees with the findings of previous reviews.[19,21] Only maxillary perimeter was judged to be clinically significant when was compared between digital and plaster models according to Luu et al.[18] The intraclass correlation coefficient for this measurement was poor when evaluated in the included studies.[1,18] In the meta-analysis comparison we could observe accuracy of tooth width, and of maxillary and mandibular crowding.

Only one article[3] used Bland-Altman analysis to evaluate accuracy and reproducibility, respectively, by the degree of agreement between the measurements on digital models and those on plaster models, and between replicate measurements. Future studies could include this method that is simple, and easy to demonstrate agreement and reliability.

Most mean differences obtained from comparison measurements performed on plaster models and digital models generated from CBCT suggest that one should contraindicate this digital model to study model analysis mainly on borderline cases. Other known reasons to avoid this method were in dental arches with restorations cases,[61] and for patients with primary and mixed dentitions.[64]

The findings of reproducibility of the linear dental measurements acquired from plaster as well as CBCT digital models agree with the results of Luu et al.,[18] and Rossini et al.[19] The findings of this systematic review showed clinically insignificant mean differences for tooth size, arch width, arch length and crowding, and Bolton discrepancy, except for the overall Bolton discrepancy measured at plaster model, and for maxillary perimeter measured at digital model obtained from CBCT. This discrepancy might be caused by random errors in measurements. The correlation of repeated measures was excellent for CBCT models and for almost all repeated measures. Only upper right molar, maxillary perimeter and maxillary crowding showed good correlation for repeated measures.

Precision of 0.01 mm is adopted to take measurements in plaster models and digital models software in general,[1,3,13,14,17,32] therefore this digital models generated from CBCT are in fact limited by the resolution of CBCT scan.[3,18] These standardizations already affect the quality of the images, especially digital models generated from CBCT. All selected studies for this review used 0.3 mm^3 voxel size.[1,3,18,31,32] Added to this, the image quality might be affected by scanning artifacts, patient's movement while performing CBCT scan,[3,31] and by the poor reconstruction of occlusal surface in some cases.[3] And these problems might affect dental measurements. When the poor image quality of occlusal surface is obtained the arch width measurement would be probably questionable.

As demonstrated with this systematic review and meta-analysis, the digital models generated from CBCT are not perfect yet. We do not intend to suggest the replacement of plaster models or some digital models, that have proven to be accurate and reproducible, by models generated from CBCT, but we can advise to take the opportunity of using these models when already part of diagnostic record of the patient.

CONCLUSION

Based on moderate level of evidence, it may be concluded:

- Digital models obtained from cone beam computed tomography are accurate for the following maxillary and mandibular dental measures: crowding and mesiodistal width;
- The differences were acceptable for almost all dental linear measurements, except for the arch perimeter;
- Digital models generated from cone beam computed tomography are reproducible for all measurements.

Table 1. PECO

P- Participants / Population	Orthodontic patients who have CBCT scan
E- Exposure	CBCT performed for orthodontic treatment planning
C- Comparison	Among dental linear measurements of digital study models generated from CBCT and plaster models of the same subject
O- "Outcome"	Accuracy and reproducibility of dental linear measurements of digital study models generated from CBCT
Question	Are dental linear measurements obtained from digital study models generated from CBCT accurate and reproducible compared with the same measurements obtained from the plaster models?

Table 2. Search strategy for Medline database (via Pubmed)

Medline	(((((((((Orthodontics[MeSH Terms]) OR Odontometry[MeSH Terms]) OR "Dental Arch"[MeSH Terms]) OR Orthodontic[Title/Abstract]) OR Odontometry[Title/Abstract]) OR Skulls[Title/Abstract]) OR Teeth[Title/Abstract])) AND ((((("Cone-Beam Computed Tomography"[MeSH Terms]) OR "Imaging, Three-Dimensional"[MeSH Terms]) OR "Cone-Beam Computed Tomography"[Title/Abstract]) OR "Three-Dimensional Imaging"[Title/Abstract]) OR CBCT[Title/Abstract]) OR 3D[Title/Abstract])) AND ((((((((("Dental Models"[MeSH Terms]) OR "Image Processing, Computer-assisted"[MeSH Terms]) OR "Dental Models"[Title/Abstract]) OR "Dental Casts"[Title/Abstract]) OR "Digital Models"[Title/Abstract]) OR "Digital Model"[Title/Abstract]) OR "Study Models"[Title/Abstract]) OR "Virtual Models"[Title/Abstract]) OR "Plaster Models"[Title/Abstract])

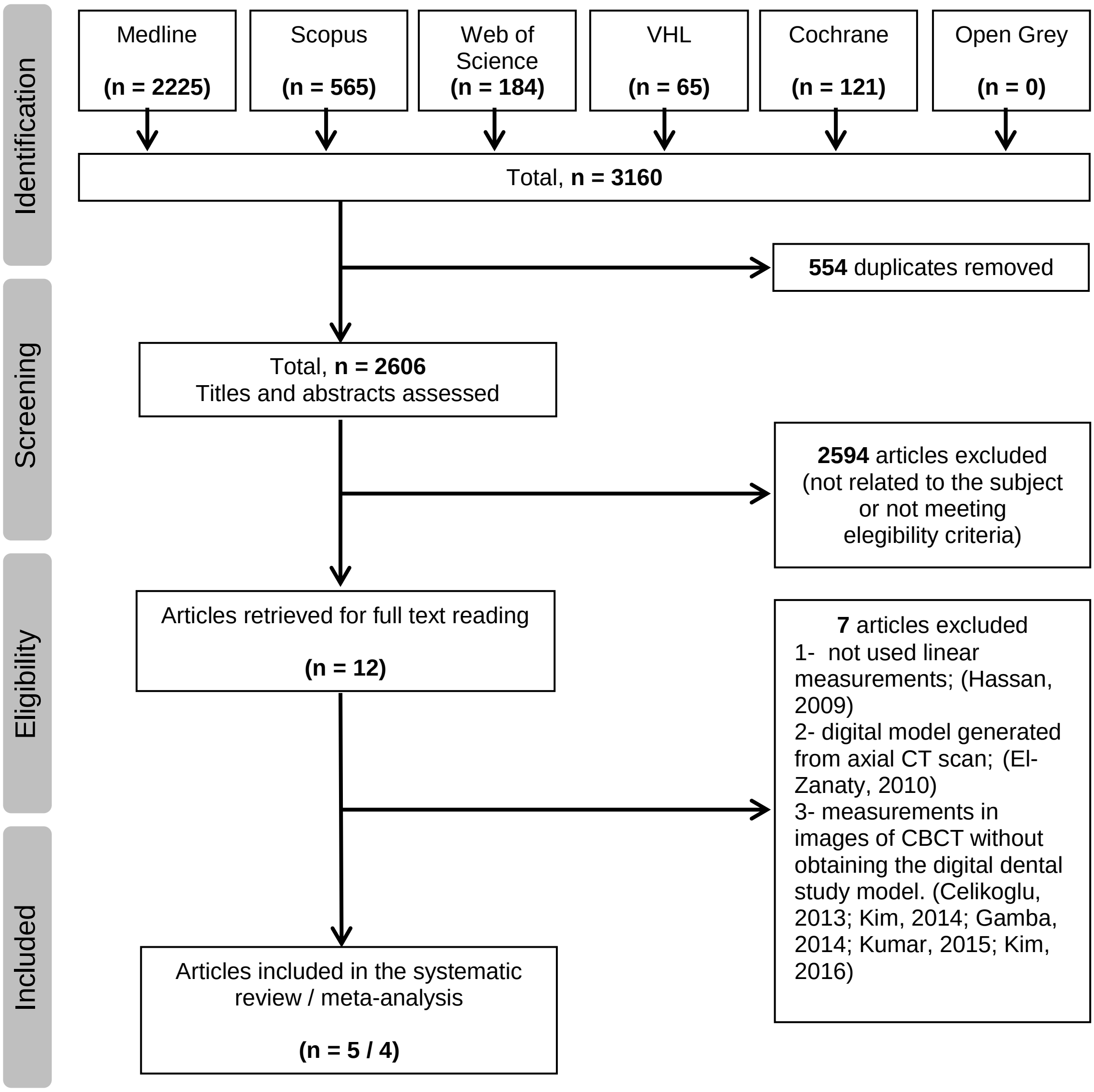


Figure 1. Flow diagram of selected studies (PRISMA)

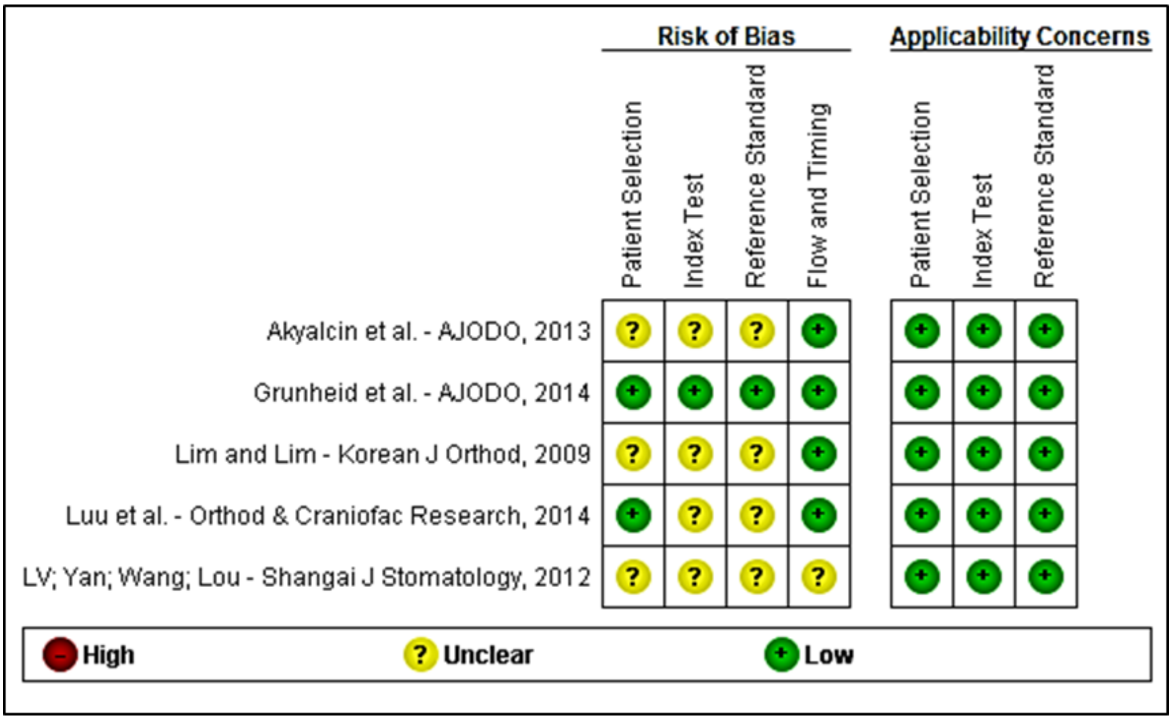


Figure 2. Risk of bias and applicability concerns summary

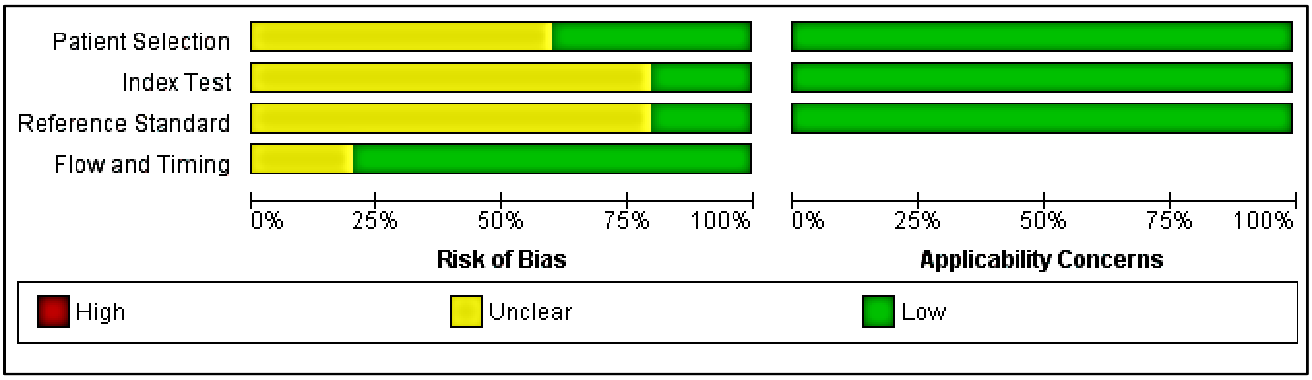
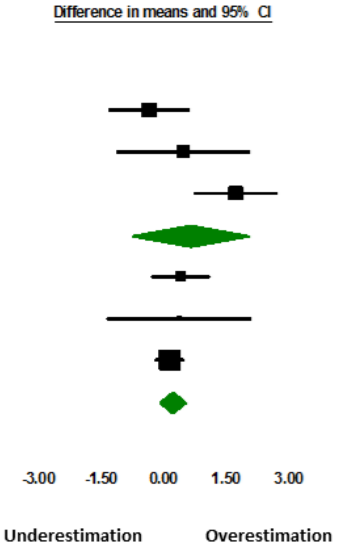


Figure 3. Risk of bias and applicability concerns graph

Group by Subgroup within study	Study name	Subgroup within study	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
			Statistics for each study						
Mandibular arch	Lim and Lim, 2009	Mandibular arch	-0.320	0.496	0.246	-1.293	0.653	-0.645	0.519
Mandibular arch	Alyacin et al, 2013	Mandibular arch	0.500	0.813	0.662	-1.094	2.094	0.615	0.539
Mandibular arch	Luu et al, 2014	Mandibular arch	1.750	0.505	0.255	0.760	2.740	3.466	0.001
Mandibular arch			0.653	0.703	0.495	-0.725	2.031	0.929	0.353
Maxillary arch	Lim and Lim, 2009	Maxillary arch	0.430	0.357	0.128	-0.270	1.130	1.203	0.229
Maxillary arch	Alyacin et al, 2013	Maxillary arch	0.400	0.884	0.781	-1.332	2.132	0.453	0.651
Maxillary arch	Luu et al, 2014	Maxillary arch	0.170	0.176	0.031	-0.176	0.516	0.964	0.335
Maxillary arch			0.226	0.156	0.024	-0.079	0.532	1.455	0.146



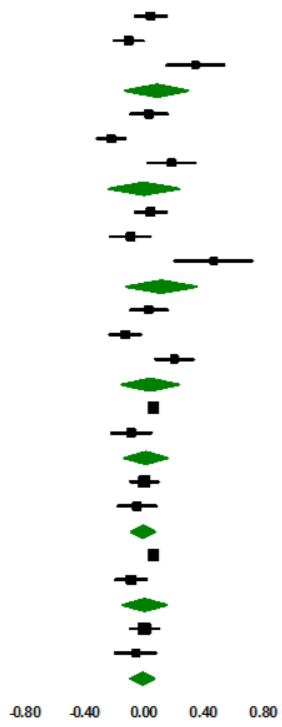
Heterogeneity: Mandibular arch (crowding) - Q-value: 8.596, p-value:0.014, I2: 76.73, Tau2: 1.11 Tau: 1.058 /
Maxillary arch (crowding) - Q-value: 0.46, p-value: 0.792, I2: 0.00, Tau2: 0.00, Tau: 0.00

Figure 4. Comparison of crowding measurement obtained on digital model generated from CBCT and plaster model

Group by Subgroup within study	Study name	Subgroup within study	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
11.00	Lim and Lim, 2009	11.000	0.050	0.057	0.003	-0.062	0.162	0.878	0.380
11.00	Lv et al, 2012	11.000	-0.095	0.053	0.003	-0.200	0.010	-1.778	0.075
11.00	Luu et al, 2014	11.000	0.350	0.101	0.010	0.152	0.548	3.466	0.001
11.00			0.086	0.108	0.012	-0.126	0.297	0.794	0.427
12.00	Lim and Lim, 2009	12.000	0.040	0.066	0.004	-0.090	0.170	0.602	0.547
12.00	Lv et al, 2012	12.000	-0.211	0.052	0.003	-0.314	-0.108	-4.020	0.000
12.00	Luu et al, 2014	12.000	0.190	0.086	0.007	0.022	0.358	2.211	0.027
12.00			-0.001	0.119	0.014	-0.235	0.233	-0.006	0.995
21.00	Lim and Lim, 2009	21.000	0.050	0.057	0.003	-0.062	0.162	0.878	0.380
21.00	Lv et al, 2012	21.000	-0.083	0.072	0.005	-0.224	0.058	-1.151	0.250
21.00	Luu et al, 2014	21.000	0.470	0.136	0.018	0.204	0.736	3.466	0.001
21.00			0.115	0.120	0.014	-0.120	0.351	0.962	0.336
22.00	Lim and Lim, 2009	22.000	0.040	0.066	0.004	-0.090	0.170	0.602	0.547
22.00	Lv et al, 2012	22.000	-0.119	0.057	0.003	-0.230	-0.008	-2.102	0.036
22.00	Luu et al, 2014	22.000	0.210	0.068	0.005	0.077	0.343	3.098	0.002
22.00			0.041	0.097	0.009	-0.149	0.231	0.423	0.672
31.00	Lim and Lim, 2009	31.000	0.070	0.005	0.000	0.059	0.081	13.021	0.000
31.00	Luu et al, 2014	31.000	-0.080	0.072	0.005	-0.220	0.060	-1.116	0.264
31.00			0.012	0.073	0.005	-0.131	0.155	0.165	0.869
32.00	Lim and Lim, 2009	32.000	0.010	0.051	0.003	-0.089	0.109	0.198	0.843
32.00	Luu et al, 2014	32.000	-0.040	0.068	0.005	-0.173	0.093	-0.588	0.557
32.00			-0.008	0.041	0.002	-0.087	0.072	-0.192	0.848
41.00	Lim and Lim, 2009	41.000	0.070	0.005	0.000	0.059	0.081	13.021	0.000
41.00	Luu et al, 2014	41.000	-0.080	0.056	0.003	-0.190	0.030	-1.427	0.154
41.00			0.005	0.074	0.006	-0.140	0.151	0.072	0.942
42.00	Lim and Lim, 2009	42.000	0.010	0.051	0.003	-0.089	0.109	0.198	0.843
42.00	Luu et al, 2014	42.000	-0.050	0.074	0.005	-0.194	0.094	-0.679	0.497
42.00			-0.009	0.042	0.002	-0.091	0.073	-0.221	0.825

Statistics for each study

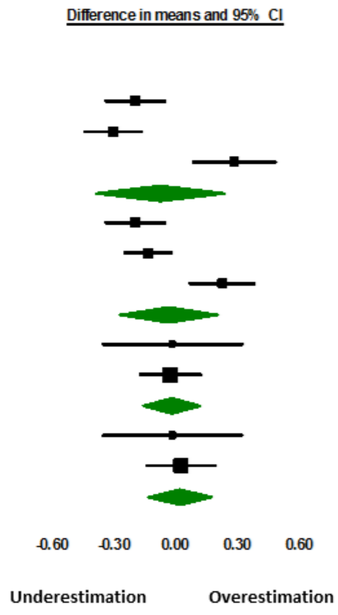
Difference in means and 95% CI



Heterogeneity: 11 (tooth) - Q-value: 15.58, p-value: 0.000, I2: 87.16, Tau2: 0.030 Tau: 0.17 /12 (tooth) - Q-value: 19.00, p-value: 0.000, I2: 89.47, Tau2: 0.038, Tau: 0,19 / 21 (tooth) - Q-value: 12.98, p-value: 0.002, I2: 84.59, Tau2: 0.35, Tau: 0.18 / 22 (tooth) - Q-value: 13.97, p-value: 0.001, I2: 85,68, Tau2: 0,024, Tau: 0.155 / 31 (tooth) - Q-value: 4.35, p-value: 0.037, I2: 77.03, Tau2: 0.009, Tau: 0.093 / 32 (tooth) - Q-value: 0.34, p-value: 0.555, I2: 0.000, Tau2: 0.000, Tau: 0.000 / 41 (tooth) - Q-value: 7.092, p-value: 0.008, I2: 85,89, Tau2: 0.010, Tau: 0.098 / 42 (tooth) - Q-value: 0.451, p-value: 0.502, I2: 0.000, Tau2: 0.000, Tau: 0.000.

Figure 5. Comparison of mesiodistal tooth width (incisors) obtained on digital model generated from CBCT and plaster model

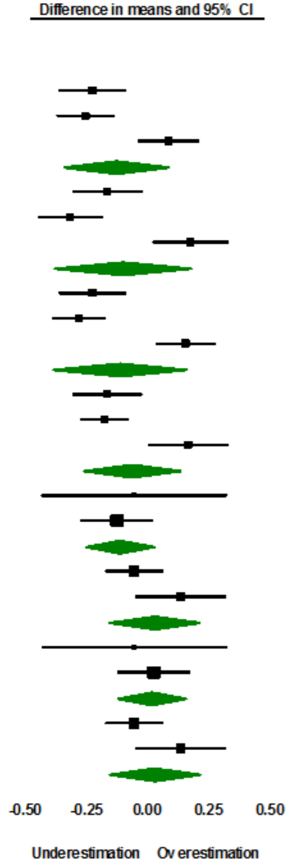
Group by Subgroup within study	Study name	Subgroup within study	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
13.00	Lim and Lim, 2009	13.000	-0.190	0.076	0.006	-0.339	-0.041	-2.503	0.012
13.00	Lv et al, 2012	13.000	-0.296	0.072	0.005	-0.438	-0.154	-4.087	0.000
13.00	Luu et al, 2014	13.000	0.290	0.104	0.011	0.087	0.493	2.796	0.005
13.00			-0.073	0.160	0.025	-0.386	0.239	-0.460	0.645
23.00	Lim and Lim, 2009	23.000	-0.190	0.076	0.006	-0.339	-0.041	-2.503	0.012
23.00	Lv et al, 2012	23.000	-0.127	0.060	0.004	-0.245	-0.009	-2.103	0.035
23.00	Luu et al, 2014	23.000	0.230	0.082	0.007	0.069	0.391	2.796	0.005
23.00			-0.033	0.120	0.015	-0.269	0.204	-0.270	0.787
33.00	Lim and Lim, 2009	33.000	-0.010	0.174	0.030	-0.351	0.331	-0.057	0.954
33.00	Luu et al, 2014	33.000	-0.020	0.077	0.006	-0.171	0.131	-0.260	0.795
33.00			-0.018	0.070	0.005	-0.156	0.120	-0.261	0.794
43.00	Lim and Lim, 2009	43.000	-0.010	0.174	0.030	-0.351	0.331	-0.057	0.954
43.00	Luu et al, 2014	43.000	0.030	0.088	0.008	-0.142	0.202	0.343	0.732
43.00			0.022	0.078	0.006	-0.131	0.175	0.280	0.779



Heterogeneity: 13 (tooth) - Q-value: 22.261, p-value: 0.000, I2: 91.016, Tau2: 0.069, Tau: 0.263 / 23 (tooth) - Q-value: 16,58, p-value: 0.000, I2: 87.94, Tau2: 0.038, Tau: 0.195 / 33 (tooth) - Q-value: 0.003, p-value: 0.958, I2: 0.00, Tau2: 0.00, Tau: 0.00 / 43 (tooth) - Q-value: 0.042, p-value: 0.837, I2: 0.00, Tau2: 0.00, Tau: 0.00.

Figure 6. Comparison of mesiodistal tooth width (canines) obtained on digital model generated from CBCT and plaster model

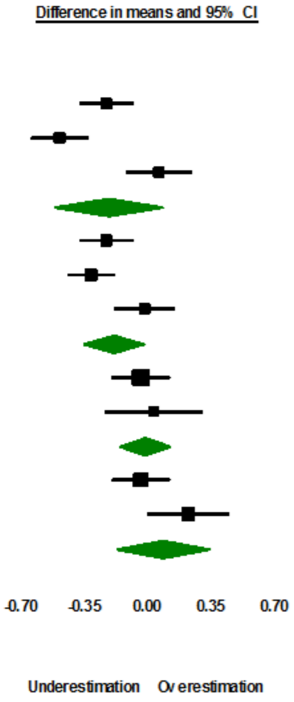
Group by Subgroup within study	Study name	Subgroup within study	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
			Statistics for each study						
14.00	Lim and Lim, 2009	14.000	-0.220	0.070	0.005	-0.356	-0.084	-3.162	0.002
14.00	Lv et al, 2012	14.000	-0.247	0.061	0.004	-0.366	-0.128	-4.068	0.000
14.00	Luu et al, 2014	14.000	0.090	0.064	0.004	-0.036	0.216	1.403	0.161
14.00			-0.126	0.109	0.012	-0.340	0.089	-1.148	0.251
15.00	Lim and Lim, 2009	15.000	-0.160	0.073	0.005	-0.303	-0.017	-2.200	0.028
15.00	Lv et al, 2012	15.000	-0.310	0.068	0.005	-0.444	-0.176	-4.538	0.000
15.00	Luu et al, 2014	15.000	0.180	0.079	0.006	0.026	0.334	2.285	0.022
15.00			-0.099	0.142	0.020	-0.377	0.179	-0.697	0.486
24.00	Lim and Lim, 2009	24.000	-0.220	0.070	0.005	-0.356	-0.084	-3.162	0.002
24.00	Lv et al, 2012	24.000	-0.274	0.056	0.003	-0.383	-0.165	-4.923	0.000
24.00	Luu et al, 2014	24.000	0.160	0.063	0.004	0.036	0.284	2.534	0.011
24.00			-0.112	0.138	0.019	-0.383	0.160	-0.806	0.420
25.00	Lim and Lim, 2009	25.000	-0.160	0.073	0.005	-0.303	-0.017	-2.200	0.028
25.00	Lv et al, 2012	25.000	-0.170	0.050	0.002	-0.267	-0.073	-3.424	0.001
25.00	Luu et al, 2014	25.000	0.170	0.083	0.007	0.007	0.333	2.039	0.041
25.00			-0.061	0.100	0.010	-0.258	0.136	-0.608	0.543
34.00	Lim and Lim, 2009	34.000	-0.050	0.193	0.037	-0.428	0.328	-0.259	0.795
34.00	Luu et al, 2014	34.000	-0.120	0.076	0.006	-0.269	0.029	-1.578	0.115
34.00			-0.111	0.071	0.005	-0.249	0.028	-1.563	0.118
35.00	Lim and Lim, 2009	35.000	-0.050	0.060	0.004	-0.168	0.068	-0.832	0.405
35.00	Luu et al, 2014	35.000	0.140	0.094	0.009	-0.045	0.325	1.485	0.138
35.00			0.031	0.094	0.009	-0.153	0.215	0.331	0.741
44.00	Lim and Lim, 2009	44.000	-0.050	0.193	0.037	-0.428	0.328	-0.259	0.795
44.00	Luu et al, 2014	44.000	0.030	0.076	0.006	-0.119	0.179	0.395	0.693
44.00			0.019	0.071	0.005	-0.119	0.158	0.273	0.785
45.00	Lim and Lim, 2009	45.000	-0.050	0.060	0.004	-0.168	0.068	-0.832	0.405
45.00	Luu et al, 2014	45.000	0.140	0.095	0.009	-0.047	0.327	1.470	0.142
45.00			0.031	0.094	0.009	-0.153	0.215	0.326	0.744



Heterogeneity: 14 (tooth) - Q-value: 17.13, p-value: 0.000, I2: 88.32, Tau2: 0.032, Tau: 0.178 / 15 (tooth) - Q-value: 22.54, p-value: 0.000, I2: 91.12, Tau2: 0.055, Tau: 0.234 / 24 (tooth) - Q-value: 29.38, p-value: 0.000, I2: 93.194, Tau2: 0.54, Tau: 0.231 / 25 (tooth) - Q-value: 13.15, p-value: 0.001, I2: 84.79, Tau2: 0.025, Tau: 0.159 / 34 (tooth) - Q-value: 0.114, p-value: 0.736, I2: 0.000, Tau2: 0.000, Tau: 0.000 / 35 (tooth) - Q-value: 2.88, p-value: 0.089, I2: 65.37, Tau2: 0.012, Tau: 0.109 / 44 (tooth) - Q-value: 0.149, p-value: 0.700, I2: 0.000, Tau2: 0.000, Tau: 0.000 / 45 (tooth) - Q-value: 2.84, p-value: 0.092, I2: 64.87, Tau2: 0.012, Tau: 0.108.

Figure 7. Comparison of mesiodistal tooth width (premolars) obtained on digital model generated from CBCT and plaster model

Group by Subgroup within study	Study name	Subgroup within study	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
16.00	Lim and Lim, 2009	16.000	-0.220	0.076	0.006	-0.369	-0.071	-2.899	0.004
16.00	Lv et al, 2012	16.000	-0.478	0.081	0.007	-0.637	-0.319	-5.882	0.000
16.00	Luu et al, 2014	16.000	0.070	0.093	0.009	-0.112	0.252	0.754	0.451
16.00			-0.212	0.151	0.023	-0.508	0.083	-1.407	0.160
26.00	Lim and Lim, 2009	26.000	-0.220	0.076	0.006	-0.369	-0.071	-2.899	0.004
26.00	Lv et al, 2012	26.000	-0.303	0.068	0.005	-0.436	-0.170	-4.457	0.000
26.00	Luu et al, 2014	26.000	-0.010	0.086	0.007	-0.179	0.159	-0.116	0.908
26.00			-0.184	0.084	0.007	-0.349	-0.020	-2.197	0.028
36.00	Lim and Lim, 2009	36.000	-0.030	0.082	0.007	-0.191	0.131	-0.365	0.715
36.00	Luu et al, 2014	36.000	0.040	0.137	0.019	-0.229	0.309	0.291	0.771
36.00			-0.012	0.071	0.005	-0.150	0.127	-0.164	0.870
46.00	Lim and Lim, 2009	46.000	-0.030	0.082	0.007	-0.191	0.131	-0.365	0.715
46.00	Luu et al, 2014	46.000	0.230	0.115	0.013	0.004	0.456	1.993	0.046
46.00			0.087	0.129	0.017	-0.166	0.341	0.675	0.499



Heterogeneity: 16 (tooth) - Q-value: 19.76, p-value: 0.000, I2: 89.88, Tau2: 0.061, Tau: 0.247 / 26 (tooth) - Q-value: 7.22, p-value: 0.027, I2: 72.32, Tau2: 0.015, Tau: 0.123 / 36 (tooth) - Q-value: 0.191, p-value: 0.662, I2: 0.000, Tau2: 0.000, Tau: 0.000 / 46 (tooth) - Q-value: 3.36, p-value: 0.067, I2: 70.29, Tau2: 0.024, Tau: 0.154.

Figure 8. Comparison of mesiodistal tooth width (molars) obtained on digital model generated from CBCT and plaster model

Table 3. Data extracted from studies included

Author, year	Sample size	Characteristics of participants	Index test / Reference standard	Examiners (readings per examiner)	Measurements	Findings
Lim and Lim, 2009[31]	20 sets of models	Orthodontic patients. Permanent dentition with no interproximal metal restorations	Accurex / Digital caliper	1 examiner (repeated twice at 2 week intervals)	Maxillary and mandibular arch: tooth size (first molar to first molar), sum of anterior teeth, sum of all teeth, required space, available space, arch length discrepancy, intercanine width, intermolar width and Bolton discrepancy (anterior and overall)	CBCT images showed significantly smaller overall Bolton discrepancy measurements. The ranges of measurements errors of the digital models generated from CBCT were clinically acceptable. These models can be used for model analysis.
Lv et al, 2012[32]	20 upper models	Orthodontic patients with fully erupted permanent dentitions. crowding up to 5 mm	Mimics / Digital caliper	1 examiner (second measurement made 2 weeks later)	Tooth crown widths, dental arch width, dental arch length and crowding	The consistency of the results was high, and some differences were accepted clinically. Therefore, it is possible to substitute PM for digital models obtained from CBCT. The ICC from repeated measurements was larger than 0.75. The measurements obtained from these digital models were smaller than on PM.
Akyalcin et al, 2013[1]	30 sets of models	Orthodontic patients between the ages of 14 and 30 years, and without metal restorations	Rapidiform / Digital caliper	2 examiners working independently (repeated all measurements twice 3 to 4 weeks later)	Maxillary and mandibular arch-length discrepancies (crowding)	The findings demonstrated that CBCT-generated models are not perfect yet: mean bias (-0.45 ± 1.10) and confidence interval (-2.65 to 1.74). The correlation between CBCT-generated models and PM is 0.85.
Grünheid et al, 2014[3]	30 upper models	Patients with variety of typical malocclusions, fully erupted permanent dentitions including incisors, canines, premolars, and first molars	AnatoModels / Digital calipers	3 (second measurement made 3 weeks later in 6 cases randomly selected)	Mesiodistal tooth-width	The bias, limit of agreement interval and mean squared error from repeatability comparisons of measurements performed on PM were 0.048 mm, 0.704 mm, and 0.035 mm, respectively and the values for their comparisons in digital models generated from CBCT were 0.06 mm, 0.987 mm and 0.063 mm. The bias, limit of agreement

						interval and mean squared error from comparison of measurements obtained from PM and digital models generated from CBCT were 0.191 mm, 1.521 mm, and 0.181 mm, respectively.
Luu et al, 2014[18]	30 sets of models	Patients with fully erupted permanent dentition	Anatomodels / Digital caliper	5 (one examiner repeated the measurements in 10 subjects five times at intervals of 10 days, with assessments limited to five cases per day)	Intermolar width, intercanine width, mesiodistal widths, arch perimeter, arch crowding, Bolton 6, Bolton 12, overbite, and overjet.	SMA using digital models obtained from CBCT was reliable but not always valid when compared with PM. The validity of measurements on digital models compared with PM showed low mean differences . The ICC demonstrated excellent intraexaminer reproducibility, and good to excellent interexaminer reproducibility.

Cone Beam Computed Tomography (CBCT); Plaster model (PM); Study model analysis (SMA); Anterior Bolton ratio (ABR); Overall Bolton ratio (OBR)

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4. CONCLUSÃO

Com base em um nível de evidência moderada, pode-se concluir que:

- Modelos digitais obtido da tomografia computadorizada de feixe cônico são acurados para as seguintes medidas dentárias maxilares: apinhamento e largura mesiodistal de incisivos e caninos;
- As diferenças foram aceitáveis para quase todas as medidas dentárias lineares, exceto para perímetro do arco e largura mesiodistal de pré-molar e molar;
- Modelos digitais gerados da tomografia computadorizada de feixe cônico são reprodutíveis para todas as medidas.

Risco de viés	**Preocupação com aplicabilidade**
Seleção de pacientes	Seleção de pacientes
Foi incluída amostra randomizada ou consecutiva?	Há preocupação sobre o espectro de pacientes incluídos não estar de acordo com a pergunta da revisão?
Foi evitado um desenho de estudo tipo caso-controle?	
O estudo evitou exclusões inapropriadas?	
Teste avaliado	Teste avaliado
O teste avaliado foi interpretado sem o conhecimento dos resultados do padrão de referência?	Há preocupação sobre o teste avaliado, sua condução ou interpretação diferirem da pergunta da revisão?
O teste avaliado foi interpretado sem o conhecimento dos resultados do padrão de referência?	
O campo de visão foi descrito?	
O scanner da TCFC foi descrito?	
O tamanho do voxel foi descrito?	
O software de aquisição de modelo digital foi descrito?	
O software para medição de modelo foi descrito?	
Padrão de referência	Padrão de referência

O padrão de referência é adequado para classificar a condição alvo?	Há preocupação sobre o padrão referência, sua condução ou interpretação não se correlacionar com a pergunta da revisão?
O padrão referência foi interpretado sem o conhecimento dos resultados do teste avaliado?	
Fluxo e tempo	
O intervalo de tempo decorrido entre a realização do teste avaliado e o padrão de referência foi adequado?	
Todos os pacientes foram submetidos ao padrão referência?	
Todos os pacientes foram incluídos na análise?	

Anexo 1. Avaliação de estudos de acurácia diagnóstica adaptado (QUADAS-2 adaptado)

Signaling question	Lim and Lim, 2009[31]	Lv et al, 2012[32]	Akyalcin et al, 2013[1]	Grunheid et al, 2014[3]	Luu et al, 2014[18]
Was a consecutive or random sample of patients enrolled?	Unclear	Unclear	Unclear	Yes	Yes
Was a case-control design avoided?	Yes	Yes	Yes	Yes	Yes
Did the study avoid inappropriate exclusions?	Yes	Yes	Yes	Yes	Yes
Were the index test results interpreted without knowledge of the results of the reference standard?	Unclear	Unclear	Unclear	Yes	Yes
Was field of view described?	Yes	Yes	Yes	Yes	Unclear
Was CBCT scanner described?	Yes	Yes	Yes	Yes	Yes
Was voxel size described?	Yes	Yes	Yes	Yes	Yes
Was type of software models acquisition described?	Yes	Yes	Yes	Yes	Yes
Was type of software models measurements described?	Yes	Yes	Yes	Yes	Yes

Is the reference standard likely to correctly classify the target condition?	Yes	Yes	Yes	Yes	Yes
Were the reference standard results interpreted without knowledge of the results of the index tests?	Unclear	Unclear	Unclear	Yes	Unclear
Was there an appropriate interval between index test and reference standard?	Yes	Unclear	Yes	Yes	Yes
Did all patients receive the same reference standard?	Yes	Yes	Yes	Yes	Yes
Were all patients included in the analysis?	Yes	Yes	Yes	Yes	Yes

[a] Adapated from Whting PF, Rutjes AWS, Westwood, ME, Mallet, S, Deeks, JJ et al. QUADAS-2: A Revised Tool for the Quality Assessment of Diagnostic Accuracy Studies. *Ann Intern Med*. 2011;155:529-536. Available from: http://annals.org.

Anexo 2. Quality Assessement of Included Studies[a]

Author, Year	Sample	Measurements	Difference-mm (SD)	Confidence interval (CI)	Statistical significance	Bias -mm (SD)	Mean squared error	Limit of agreement interval width (mm)
Lim and Lim, 2009	20 sets of models	*Maxillary arch*						
		Central incisor	0.05 (0.18)					
		Lateral incisor	0.04 (0.21)					
		Canine	-0.19 (0.24)		$p < 0.001$			
		1st Premolar	-0.22 (0.22)		$p < 0.001$			
		2nd Premolar	-0.16 (0.23)		$p < 0.01$			
		1st Molar	-0.22 (0.24)		$p < 0.01$			
		Sum of anterior teeth	-0.19 (0.66)					
		Sum of all teeth	-1.38 (1.19)		$p < 0.001$			
		Required space	-0.96 (1.07)		$p < 0.01$			
		Available space	-0.52 (0.51)		$p < 0.001$			
		Arch length discrepancy	0.43 (1.13)					
		Intercanine width	-0.46 (0.42)		$p < 0.001$			
		Intermolar width	-0.22 (1.33)					
		Mandibular arch						
		Central incisor	0.07 (0.17)		$p < 0.05$			
		Lateral incisor	0.01 (0.16)					
		Canine	-0.01 (0.55)					
		1st Premolar	-0.05 (0.61)					
		2nd Premolar	-0.05 (0.19)					
		1st Molar	-0.03 (0.26)					
		Sum of anterior teeth	0.12 (0.89)					
		Sum of all teeth	-0.12 (1.56)					
		Required space	-0.22 (1.38)					
		Available space	-0.55 (0.57)		$p < 0.001$			
		Arch length discrepancy	-0.32 (1.57)					
		Intercanine width	-0.16 (0.69)					
		Intermolar width	0.01 (0.57)					
		Bolton discrepancy						
		Anterior	-0.35 (1.31)					
		Overall	-1.25 (2.08)		$p < 0.05$			

Lv et al, 2012[32]	20 upper models	Maxillary right central incisor	0.095 (0.169)		$p < 0.05$			
		Maxillary right lateral incisor	0.211 (0.166)		$p < 0.05$			
		Maxillary right canine	0.296 (0.229)		$p < 0.05$			
		Maxillary right 1^{o} premolar	0.247 (0.192)		$p < 0.05$			
		Maxillary right 2^{o} premolar	0.310 (0.216)		$p < 0.05$			
		Maxillary right 1^{o} molar	0.478 (0.257)		$p < 0.05$			
		Maxillary left central incisor	0.083 (0.228)					
		Maxillary left lateral incisor	0.119 (0.179)		$p < 0.05$			
		Maxillary left canine	0.127 (0.191)		$p < 0.05$			
		Maxillary left 1^{o} premolar	0.274 (0.176)		$p < 0.05$			
		Maxillary left 2^{o} premolar	0.170 (0.157)		$p < 0.05$			
		Maxillary left 1^{o} molar	0.303 (0.215)		$p < 0.05$			
		Interpremolar width	0.093 (0.214)					
		Intermolar width	0.144 (0.427)					
		Segment ICD	0.236 (0.541)					
		Segment CPD	0.286 (0.264)		$p < 0.05$			
		Segment ICE	0.059 (0.457)					
		Segment CPE	0.288 (0.239)		$p < 0.05$			
		Apinhamento	1.064 (1.002)		$p < 0.05$			
Akyalcin et al, 2013[1]	30 sets of models	Arch length discrepancy in both arches		-2.65, 1.74		-0.45 (1.10)		
Grünheid et al, 2014[3]	30 upper models	Mesiodistal tooth-width				0.191	0.181	1.521
Luu et al, 2014[18]	30 sets of models	Tooth 1-1	0.35	0.16, 0.54	$p < 0.05$			
		Tooth 1-2	0.19	0.02, 0.37	$p < 0.05$			
		Tooth 1-3	0.29	0.09, 0.49	$p < 0.05$			
		Tooth 1-4	0.09	-0.04, 0.22				
		Tooth 1-5	0.18	0.02, 0.33	$p < 0.05$			
		Tooth 1-6	0.07	-0.12, 0.27				
		Tooth 2-1	0.47	0.27, 0.67	$p < 0.05$			
		Tooth 2-2-	0.21	0.08, 0.34	$p < 0.05$			

		Tooth 2-3	0.23	0.07, 0.39	$p < 0.05$			
		Tooth 2-4	0.16	0.03, 0.28	$p < 0.05$			
		Tooth 2-5	0.17	0.00, 0.34	$p < 0.05$			
		Tooth 2-6	-0.01	-0.2, 0.19				
		Tooth 3-1	-0.08	-0.23, 0.07				
		Tooth 3-2	-0.04	-0.16, 0.09				
		Tooth 3-3	-0.02	-0.18, 0.14				
		Tooth 3-4	-0.12	-0.28, 0.03				
		Tooth 3-5	0.14	-0.05, 0.34				
		Tooth 3-6	0.04	-0.22, 0.30				
		Tooth 4-1	-0.08	-0.20, 0.03				
		Tooth 4-2	-0.05	-0.18, 0.09				
		Tooth 4-3	0.03	-0.14, 0.20				
		Tooth 4-4	0.03	-0.14, 0.21				
		Tooth 4-5	0.14	-0.05, 0.33				
		Tooth 4-6	0.23	-0.00, 0.47				
		Maxillary intermolar width	0.17	-0.19, 0.54				
		Maxillary intercanine width	0.14	-0.42, 0.71				
		Mandibular intermolar width	0.39	0.05, 0.73	$p < 0.05$			
		Mandibular intercanine width	0.29	-0.01, 0.59				
		Maxillary arch perimeter	3.38	2.48, 4.28	$p < 0.05$			
		Maxillary arch crowding	1.06	0.18, 1.94	$p < 0.05$			
		Mandibular arch perimeter	1.71	0.88, 2.54	$p < 0.05$			
		Mandibular arch crowding	1.75	1.00, 2.49	$p < 0.05$			
		Bolton 6	-1.57	-1.99, -1.16	$p < 0.05$			
		Bolton 12	-1.95	-2.73, -1.17	$p < 0.05$			

Segment ICD: distance between central right incisor to right canine; segment CPD: distance between right canine to 2^{o} right premolar; segment ICE: distance between central left incisor to left canine; segment CPE: distance between left canine to 2^{o} left premolar.

Anexo 3. Accuracy, Digital model generated from CBCT vs Plaster: Difference, Confidence Interval, Statistical Significance, Bias, Mean Squared Error, Limit of Agreement Interval Width.

Author, Year	Measurements	ICC	Confidence interval (CI)	Pearson Correlation	Mean difference (mm)	Absolute differences - mm	Statistical significance	Bias (mm)	Mean squared error	Limit of agreement interval width (mm)
Lim and Lim, 2009[31]	**Digital Model**									
	Maxillary arch									
	Central incisor					0.20 (0.16)				
	Lateral incisor					0.18 (0.15)				
	Canine					0.17 (0.11)				
	1st Premolar					0.19 (0.13)				
	2nd Premolar					0.18 (0.16)				
	1st Molar					0.26 (0.21)				
	Sum of anterior teeth					0.62 (0.33)				
	Sum of all teeth					1.06 (0.68)				
	Required space					0.86 (0.50)				
	Available space					0.25 (0.25)				
	Arch length discrepancy					0.77 (0.63)				
	Intercanine width					0.49 (0.37)				
	Intermolar width					0.37 (0.27)				
	Mandibular arch									
	Central incisor									
	Lateral incisor					0.15 (0.12)				
	Canine					0.21 (0.18)*	$p < 0.05$			
	1st Premolar					0.16 (0.14)				
	2nd Premolar					0.18 (0.18)				
	1st Molar					0.22 (0.20)*	$p < 0.05$			
	Sum of anterior teeth					0.20 (0.17)				
	Sum of all teeth					0.43 (0.42)				
	Required space					0.83 (0.63)				
	Available space					0.65 (0.41)				
	Arch length discrepancy					0.28 (0.22)				
	Intercanine width					0.65 (0.52)				
	Intermolar width					0.34 (0.28)				
						0.40 (0.34)				
	Bolton discrepancy									
	Anterior					0.75 (0.74)				
	Overall					1.34 (1.63)				

Lv et al., 2012[32]	All measurements	0.75		p < 0.01						
Akyalcin et al, 2013[1]	All measurements	>0.92								
Grünheid et al., 2014[3]								0.006	0.063	0.987
Luu et al., 2014[18]	**Digital model**				worst best					
	Tooth 1-1	0.871	0.723, 0.960		0.10 0.01					
	Tooth 1-2	0.975	0.940, 0.993		0.03 0.00					
	Tooth 1-3	0.916	0.813, 0.975		0.10 0.01					
	Tooth 1-4	0.919	0.818, 0.976		0.06 0.00					
	Tooth 1-5	0.927	0.835, 0.978		0.09 0.00					
	Tooth 1-6	0.913	0.799, 0.974		0.28 0.05		$p < 0.05$			
	Tooth 2-1	0.962	0.911, 0.989		0.12 0.00					
	Tooth 2-2-	0.965	0.917, 0.990		0.12 0.00					
	Tooth 2-3	0.920	0.820, 0.976		0.09 0.00					
	Tooth 2-4	0.915	0.809, 0.975		0.06 0.00					
	Tooth 2-5	0.898	0.777, 0.969		0.10 0.00					
	Tooth 2-6	0.863	0.711, 0.958		0.19 0.01					
	Tooth 3-1	0.962	0.909, 0.989		0.04 0.00					
	Tooth 3-2	0.905	0.790, 0.972		0.06 0.01					
	Tooth 3-3	0.876	0.734, 0.962		0.12 0.01					
	Tooth 3-4	0.813	0.623, 0.940		0.13 0.01					
	Tooth 3-5	0.894	0.767, 0.968		0.09 0.01					
	Tooth 3-6	0.919	0.819, 0.976		0.08 0.00					
	Tooth 4-1	0.945	0.873, 0.984		0.07 0.01					
	Tooth 4-2	0.957	0.900, 0.987		0.06 0.00					
	Tooth 4-3	0.866	0.716, 0.959		0.11 0.00					
	Tooth 4-4	0.867	0.717, 0.959		0.17 0.00					
	Tooth 4-5	0.977	0.944, 0.993		0.07 0.01					
	Tooth 4-6	0.902	0.784, 0.970		0.15 0.00					
	Maxillary intermolar width	0.984	0.959, 0.995		0.52 0.09		$p < 0.05$			
	Maxillary intercanine width	0.934	0.849, 0.980		0.31 0.03					
	Mandibular intermolar width	0.965	0.918, 0.990		0.27 0.00					

	Mandibular intercanine width	0.968	0.924, 0.991		0.32	0.02					
	Maxillary arch perimeter	0.929	0.802, 0.980		1.71	0.04		$p < 0.001$			
	Maxillary arch crowding	0.889	0.746, 0.967		1.47	0.03		$p < 0.05$			
	Mandibular arch perimeter	0.934	0.850, 0.981		0.82	0.09					
	Mandibular arch crowding	0.920	0.820, 0.976		1.10	0.01					
	Bolton 6	0.936	0.853, 0.981		0.30	0.01					
	Bolton 12	0.887	0.775, 0.966		0.78	0.13					
	Plaster models										
	Tooth 1-1				worst	best					
	Tooth 1-2	0.980	0.946, 0.995		0.13	0.01		$p < 0.05$			
	Tooth 1-3	0.989	0.973, 0.997		0.07	0.00					
	Tooth 1-4	0.940	0.862, 0.982		0.08	0.00					
	Tooth 1-5	0.946	0.875, 0.984		0.05	0.01					
	Tooth 1-6	0.949	0.878, 0.985		0.12	0.02		$p < 0.05$			
	Tooth 2-1	0.931	0.841, 0.980		0.13	0.01					
	Tooth 2-2	0.990	0.976, 0.997		0.05	0.00					
	Tooth 2-3	0.980	0.949, 0.994		0.14	0.03		$p < 0.05$			
	Tooth 2-4	0.936	0.855, 0.981		0.08	0.00					
	Tooth 2-5	0.830	0.651, 0.946		0.15	0.01					
	Tooth 2-6	0.960	0.906, 0.988		0.09	0.00					
	Tooth 3-1	0.784	0.537, 0.930		0.08	0.00					
	Tooth 3-2	0.971	0.932, 0.992		0.05	0.00					
	Tooth 3-3	0.970	0.925, 0.991		0.09	0.01		$p < 0.05$			
	Tooth 3-4	0.942	0.867, 0.983		0.10	0.00					
	Tooth 3-5	0.901	0.781, 0.970		0.04	0.00					
	Tooth 3-6	0.847	0.677, 0.952		0.05	0.00					
	Tooth 4-1	0.937	0.852, 0.982		0.21	0.02					
	Tooth 4-2	0.902	0.782, 0.970		0.07	0.00					
	Tooth 4-3	0.941	0.864, 0.982		0.06	0.00					
	Tooth 4-4	0.952	0.887, 0.986		0.12	0.01					
	Tooth 4-5	0.945	0.873, 0.984		0.05	0.00					
	Tooth 4-6	0.901	0.782, 0.970		0.14	0.00					
	Maxillary intermolar width	0.964	0.916, 0.990		0.10	0.01					
	Maxillary intercanine width	0.992	0.981, 0.998		0.18	0.04					
	Mandibular intermolar width	0.985	0.963, 0.996		0.11	0.01					
	Mandibular intercanine width	0.977	0.945, 0.993		0.13	0.00					
	Maxillary arch perimeter	0.978	0.947, 0.994		0.15	0.01					
	Maxillary arch crowding	0.794	0.593, 0.934		1.33	0.04					
	Mandibular arch perimeter	0.735	0.502, 0.934		1.31	0.16					
	Mandibular arch crowding	0.927	0.833, 0.978		0.76	0.02					
	Bolton 6	0.915	0.799, 0.975		1.27	0.16		$p < 0.05$			
	Bolton 12	0.934	0.848, 0.980		0.18	0.01					

		0.899	0.779, 0.970		0.36	0.04					

ICC: intraclass correlation coefficient

Anexo 4. Intraexaminer reproducibility, Digital model generated from CBCT and Plaster: ICC, Pearson Correlation, Mean Difference, Absolute Difference, Statistical Significance, Bias, Mean Squared Error, Limit of Agreement Interval Width.

Author, Year	Parameters	ICC	Confidence interval (CI)	Mean difference (mm)	Statistical significance	Bias (mm)	Mean squared error	Limit of agreement interval width (mm)
Akyalcin et al, 2013[1]		>0.92						
Grünheid et al., 2014[3]	**Digital model**							
	1 VS 2					0.912	1.200	2.408
	1 VS 3					0.035	0.141	1.330
	2 VS 3					-0.877	1.092	2.214
	Plaster model							
	1 VS 2					0.413	0.402	1.891
	1 VS 3					0.284	0.227	1.464
	2 VS 3					-0.128	0.138	1.370
Luu et al., 2014[18]	**Digital model**			worst best				
	Tooth 1-1	0.909	0.797, 0.973	0.09 0.01				
	Tooth 1-2	0.939	0.857, 0.982	0.24 0.02				
	Tooth 1-3	0.771	0.556, 0.925	0.19 0.01				
	Tooth 1-4	0.795	0.592, 0.934	0.23 0.01				
	Tooth 1-5	0.818	0.631, 0.942	0.21 0.02				
	Tooth 1-6	0.867	0.718, 0.959	0.16 0.01				
	Tooth 2-1	0.904	0.787, 0.971	0.17 0.02				
	Tooth 2-2	0.619	0.351, 0.862	0.38 0.01				
	Tooth 2-3	0.771	0.505, 0.928	0.34 0.03	$p < 0.05$			
	Tooth 2-4	0.734	0.500, 0.910	0.17 0.01				
	Tooth 2-5	0.691	0.431, 0.894	0.32 0.01	$p < 0.05$			
	Tooth 2-6	0.735	0.497, 0.912	0.11 0.00				
	Tooth 3-1	0.942	0.866, 0.983	0.15 0.01				
	Tooth 3-2	0.684	0.412, 0.892	0.31 0.01	$p < 0.05$			
	Tooth 3-3	0.850	0.684, 0.954	0.07 0.01				
	Tooth 3-4	0.559	0.289, 0.830	0.32 0.00				
	Tooth 3-5	0.771	0.556, 0.925	0.21 0.00				
	Tooth 3-6	0.815	0.627, 0.941	0.23 0.01				
	Tooth 4-1	0.808	0.610, 0.939	0.23 0.00	$p < 0.05$			
	Tooth 4-2	0.827	0.647, 0.945	0.18 0.01				
	Tooth 4-3	0.799	0.600, 0.935	0.13 0.03				

	Tooth 4-4	0.739	0.508, 0.913	0.17	0.01				
	Tooth 4-5	0.818	0.631, 0.942	0.21	0.03				
	Tooth 4-6	0.729	0.495, 0.908	0.28	0.04				
	Maxillary intermolar width	0.837	0.663, 0.949	0.75	0.05	$p < 0.05$			
	Maxillary intercanine width	0.749	0.524, 0.916	1.11	0.07				
	Mandibular intermolar width	0.860	0.701, 0.957	1.17	0.02				
	Mandibular intercanine width	0.934	0.832, 0.981	0.72	0.02	$p < 0.05$			
	Maxillary arch perimeter	0.679	0.268, 0.902	5.72	0.13	$p < 0.05$			
	Maxillary arch crowding	0.566	0.188, 0.849	5.51	0.87	$p < 0.05$			
	Mandibular arch perimeter	0.776	0.495, 0.931	3.03	0.08	$p < 0.05$			
	Mandibular arch crowding	0.742	0.481, 0.916	3.00	0.11	$p < 0.05$			
	Bolton 6	0.884	0.749, 0.964	0.39	0.06				
	Bolton 12	0.833	0.654, 0.947	0.54	0.01				
	Plaster model								
	Tooth 1-1	0.923	0.826, 0.977	0.15	0.01				
	Tooth 1-2	0.639	0.377, 0.870	0.39	0.01				
	Tooth 1-3	0.712	0.470, 0.902	0.13	0.02				
	Tooth 1-4	0.830	0.649, 0.946	0.22	0.03				
	Tooth 1-5	0.856	0.697, 0.955	0.18	0.00				
	Tooth 1-6	0.823	0.624, 0.945	0.34	0.01	$p < 0.05$			
	Tooth 2-1	0.949	0.883, 0.985	0.11	0.01				
	Tooth 2-2	0.965	0.917, 0.990	0.07	0.00				
	Tooth 2-3	0.587	0.318, 0.845	0.25	0.00				
	Tooth 2-4	0.841	0.657, 0.951	0.22	0.01	$p < 0.05$			
	Tooth 2-5	0.866	0.715, 0.959	0.14	0.01				
	Tooth 2-6	0.702	0.458, 0.897	0.31	0.06				
	Tooth 3-1	0.842	0.669, 0.951	0.06	0.00				
	Tooth 3-2	0.900	0.780, 0.970	0.13	0.00				
	Tooth 3-3	0.890	0.760, 0.967	0.07	0.01				
	Tooth 3-4	0.874	0.704, 0.963	0.23	0.02	$p < 0.05$			
	Tooth 3-5	0.843	0.672, 0.951	0.20	0.00				
	Tooth 3-6	0.810	0.597, 0.941	0.45	0.06	$p < 0.05$			
	Tooth 4-1	0.935	0.851, 0.981	0.10	0.02				
	Tooth 4-2	0.855	0.693, 0.955	0.06	0.00				
	Tooth 4-3	0.888	0.753, 0.966	0.19	0.03				
	Tooth 4-4	0.875	0.719, 0.962	0.22	0.01	$p < 0.05$			
	Tooth 4-5	0.834	0.659, 0.948	0.18	0.01				
	Tooth 4-6	0.826	0.613, 0.947	0.36	0.01	$p < 0.05$			
	Maxillary intermolar width	0.854	0.683, 0.955	1.93	0.05				
	Maxillary intercanine width	0.957	0.893, 0.988	0.52	0.09	$p < 0.05$			
	Mandibular intermolar width	0.939	0.859, 0.982	0.45	0.04				
	Mandibular intercanine width	0.905	0.775, 0.972	0.92	0.06	$p < 0.05$			

	Maxillary arch perimeter	0.838	0.551, 0.955	3.07	0.01	$p < 0.05$			
	Maxillary arch crowding	0.787	0.548, 0.933	1.94	0.01	$p < 0.05$			
	Mandibular arch perimeter	0.522	0.195, 0.819	4.66	0.32	$p < 0.05$			
	Mandibular arch crowding	0.655	0.345, 0.882	3.66	0.15	$p < 0.05$			
	Bolton 6	0.721	0.476, 0.906	0.10	0.01				
	Bolton 1	0.811	0.620, 0.939	0.75	0.02				

ICC: intraclass correlation coefficient

Anexo 5. Interexaminer reproducibility, Digital model generated from CBCT and Plaster: ICC, Confidence Interval, Mean Difference, Statistical Significance, Bias, Mean Squared Error, Limit of Agreement Interval Width.