UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
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Juliana Andréa Corrêa Travessas

AVALIAÇÃO DE VOLUME EM IMAGENS DE TOMOGRAFIA COMPUTADORIZADA – REVISÃO SISTEMÁTICA DA LITERATURA E ESTUDO EXPERIMENTAL IN VITRO

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H. L. Mencken

RESUMO

As tomografias computadorizadas são exames de grande precisão utilizados para diagnóstico e planejamento em Odontologia, mas que nem sempre estão ao alcance do paciente e, portanto, do cirurgião-dentista. O desenvolvimento de tomógrafos computadorizados de feixe cônico permitiu a realização de exames tomográficos com menor exposição do paciente à radiação, mais rápidos e de menor custo, tornando-os mais acessíveis à população e com aplicabilidade em diversas áreas da odontologia. Estudos mostram que os exames de tomografia computadorizada de feixe em leque (TCFL) e de feixe cônico possibilitam mensurações de volume. Entretanto, com relação à tomografia computadorizada de feixe cônico (TCFC) ainda existe uma lacuna na literatura a respeito de pesquisas com análise de volume em diferentes condições clínicas. Assim, os objetivos deste estudo foram divididos em duas partes: uma revisão sistemática da literatura sobre este assunto e a avaliação *in vitro,* em exames de TCFC e TCFL*,* da medição de volume em espaços contendo diferentes substâncias (ar, água, propilenoglicol e tutano). A busca da revisão sistemática foi conduzida em quatro bases de dados, usando descritores de assuntos e palavras livres referentes ao assunto. Os artigos recuperados na busca tiveram título e resumo lidos por dois pesquisadores e os selecionados, de acordo com os critérios de inclusão e exclusão, tiveram seus textos lidos na íntegra para confirmar inclusão. Foram incluídos na revisão sistemática 51 artigos, os quais foram avaliados quanto ao risco de viés com a utilização de uma ferramenta adaptada, indicada para avaliação de estudos de acurácia de medidas (QUAMAS). A avaliação dos estudos sugere que medidas de volume em imagens tomográficas são acuradas. Na parte experimental foram utilizados corpos de prova de forma aproximadamente cilíndrica, obtidos com osso bovino (ossobuco), preenchidas com diferentes conteúdos. As imagens foram adquiridas com um tomógrafo de feixe em leque e cinco tomógrafos de feixe cônico. Os volumes foram determinados em dois softwares de imagem, um livre e um pago. Para analisar os resultados foi utilizado o teste ANOVA de três vias. Foi observada interação estatisticamente significativa entre software e conteúdo. Conteúdo e software influenciam na acurácia das medidas de volume, especialmente quando o conteúdo tem valores de cinza próximos aos do tecido adjacente. As amostras não preenchidas apresentaram os valores de volume mais precisos quando comparados ao padrão ouro. Sabendo-se que medidas de volume obtidas em situações simuladas podem ser consideradas acuradas, essa informação deve ser utilizada com cautela na tentativa de extrapolação para situações clínicas.

Palavras-chave: Diagnóstico por imagem. Tomografia computadorizada por raios X. Tomografia computadorizada de feixe cônico. Revisão sistemática. *Software.*

ABSTRACT

Computed tomography (CT) scans are highly accurate exams used for planning and diagnosis in dentistry, but they are not always available to the patient and, therefore, the dentist. The development of cone-beam computed tomography (CBCT) has allowed for faster and less expensive CT exposures, making them more accessible and applicable in various areas of dentistry. Studies have shown that fan-beam and CBCT examinations enable volume measurements. However, with respect to CBCT there is still a gap in the literature regarding research with volume analysis under different clinical conditions. Thus, the objectives of this study were divided into two parts, the first being a systematic review of the literature on this subject, and the second, the *in vitro* evaluation, in CBCT examinations, of volume measurement in spaces containing different substances: air, water, propylene glycol and marrow. The search for systematic review was conducted in four databases, using subject descriptors and free keywords. The articles retrieved in the search had title and abstract read by two researchers and those selected, according to the inclusion and exclusion criteria, had their texts read in full to confirm inclusion. Fifty-one articles were included in the systematic review, which were assessed for risk of bias using the adapted version of the tool Quality Assessment of Measurement Accuracy Studies (QUAMAS). Study evaluation suggests that volume measurements on tomographic images are accurate. In the experimental part, approximately cylindrical specimens obtained from bovine bone filled with different contents were used. The images were acquired with a fan beam and five CBCT. The volumes were determined in two imaging software, one free and one paid. A three-way ANOVA was conducted to determine the effects of voxel, software and content on mean volume difference concerning tomographic protocols. Content and software influences in volume measurements accuracy, especially when content has grey values close to that of the adjacent tissue. Unfilled specimens showed the most accurate volume values when compared to gold standard. As volume measurements obtained in simulated situations can be considered accurate, this information should be used with caution in the attempt to extrapolate to clinical situations.

Keywords: Diagnostic Imaging. Systematic review. Multidetector Computed Tomography. Cone-Beam Computed Tomography. Software.

LISTA DE ABREVIATURAS E SIGLAS (opcional)

ALADA - "*As Low As Diagnostically Acceptable*" – tão baixo quanto aceitável para diagnóstico

ALARA – "A*s Low As Reasonably Achievable"* – tão baixo quanto razoavelmente possível

DICOM – "*Digital Imaging and Communications in Medicine*" – Imagem Digital e Comunicação em Medicina"

FOV - field of view

kV - Quilovoltagem

mA - Miliamperagem

micro-CT - microtomografia computadorizada

TCFC – tomografia computadorizada de feixe cônico

TCFL – Tomografia computadorizada de feixe em leque

SUMÁRIO

1 INTRODUÇÃO

1.1 EXAMES POR IMAGEM

As radiografias são métodos complementares bastante utilizadas para o diagnóstico, planejamento e acompanhamento de diversos tratamentos na Odontologia(1). Essas imagens são formadas e observadas em duas dimensões, porém, utilizadas para a avaliação de estruturas tridimensionais. Consequentemente, possuem limitações inerentes ao método, como sobreposições e distorções. Isto pode levar a erros de diagnóstico ou planejamento que podem comprometer os tratamentos(2–4).

Por outro lado, as tomografias computadorizadas – técnicas que permitem reconstruções multiplanares e tridimensionais – são cada vez mais utilizadas, abrindo novas possibilidades para o diagnóstico(5–7). Apesar da sua comprovada efetividade, a tomografia de feixe em leque (TCFL) não é amplamente requisitada na prática odontológica devido ao custo elevado do aparelho e exames, disponibilidade restrita a grandes centros radiológicos médicos e ainda pela alta dose de radiação a qual o paciente é exposto(8).

A tentativa de superar inconvenientes da TCFL e a crescente demanda por melhores imagens do complexo dentomaxilofacial levou ao desenvolvimento da tomografia computadorizada de feixe cônico (TCFC)(9,10). A TCFC é uma técnica tridimensional, com baixa dose de radiação quando comparada à TCFL, permitindo a visualização de estruturas ósseas na cabeça e pescoço(11).

Muitos dos princípios e características são comuns entre os dois tipos de tomografias. Entretanto, a TCFC apresenta algumas vantagens quando comparada com a TCFL para o uso odontológico: natureza sempre isotrópica do voxel, possibilitando que as reconstruções apresentem a mesma qualidade da imagem nos diferentes planos de orientação; possibilidade de realização de exames de regiões parciais com campos de visão restritos; rapidez para a realização e reconstrução do exame; posição dos tecidos moles não modificada durante a tomada tomográfica, uma vez que o exame é realizado com o paciente sentado ou em pé; os artefatos metálicos, que causam prejuízo na imagem, são reduzidos; acesso facilitado para a rotina

odontológica, com um aparelho mais compacto do que o tomógrafo médico e redução de custos(12,13).

Apesar de todas as vantagens da TCFC, uma importante limitação é a dificuldade em estabelecer uma correlação dos níveis de cinza com a escala Hounsfield utilizada em TCFL. Alguns estudos têm sido conduzidos com a intenção de resolver esse problema, um deles observou uma forte relação entre a escala de cinza de três diferentes equipamentos de TCFC com a escala Hounsfield de um equipamento de TCFL(14). Um outro trabalho avaliando trinta protocolos em treze equipamentos de TCFC mostrou que alguns protocolos em determinados equipamentos revelam certa estabilidade quanto aos valores de cinza e que poderiam ser correlacionados com a escala Hounsfield. Porém, a escala de cinza real dependeria dos bits da imagem e da calibragem realizada pelos fabricantes, dificultando uma generalização de resultados quanto a correlação de níveis de cinza na TCFC e a escala Hounsfield(15). Um estudo de revisão concluiu que deveria ser evitado o uso de valores de cinza comparados a escala Hounsfield em TCFC, pois eles variam dependendo do equipamento, dos parâmetros utilizados, da localização espacial da região medida no FOV (field of view) e da quantidade e tipo de tecido nas regiões interna e externa do FOV(16). O estudo de Magill et al.(17) propôs uma técnica que poderia ser um ponto de partida para a conversão da escala de cinzas da TCFC para a escala Hounsfield de exames de TCFL, mostrando boa correlação de valores com o ar.

Na TCFL, a dose de radiação pode ser relativamente controlada selecionando o modo de exposição automático, que varia os parâmetros durante a exposição, de acordo com as características do paciente, garantindo que não ocorra subexposição ou exposição excessiva. Alguns equipamentos de TCFC apresentam um dispositivo semelhante que atua durante o “scout” e determina a miliamperagem (mA) tomando como base essa primeira imagem obtida(18).

O princípio de aquisição de imagem nos diferentes aparelhos de TCFC é basicamente o mesmo, independente da marca do equipamento, com algumas diferenças relacionadas aos parâmetros utilizados. Quanto à exposição, pode ser pulsada ou contínua, sendo a pulsada mais amplamente utilizada. A exposição pulsada resulta em uma grande diferença entre tempo de escaneamento e tempo de exposição, sendo o tempo de exposição consideravelmente menor, observando-se uma melhora na resolução espacial(18).

Alguns equipamentos de TCFC permitem a seleção do arco de rotação, alternando o ângulo entre 360º ou 180º, sendo que a maioria dos aparelhos realiza aquisições somente com rotação completa. A seleção da rotação parcial (180º), reduz a dose de radiação, em alguns casos, à metade, resultando, porém em perda na qualidade da imagem. Dependendo da miliamperagem, geralmente menor em uma rotação parcial, o efeito do ruído na qualidade da imagem pode ser maior ou menor(18).

A qualidade da imagem tomográfica é influenciada por tamanho de *voxel* (menor elemento de uma imagem digital tridimensional), gama dinâmica (o número de níveis de cinza), sinal e ruído. Em geral, a melhor qualidade de imagem é composta por *voxel* de pequeno tamanho, grande número de níveis de cinza e baixo ruído(19). Assim, o radiologista pode escolher a reconstrução que melhor se adapte à análise que se deseja realizar após a tomada volumétrica.

A distância do foco ao objeto e a distância do objeto ao detector são fatores que interferem na nitidez da imagem. Maiores distâncias do foco ao objeto resultam em imagens mais nítidas. Menores distâncias do objeto ao detector aumentam a radiação espalhada que atinge o detector(18).

A dose de radiação que o paciente recebe com um exame de TCFC é menor se comparada à dose da TCFL, justificando a utilização daquele exame sempre que possível. A utilização de proteção plumbífera durante o exame proporciona diminuição adicional na dose de radiação X recebida pelo paciente. Ainda, um exame de TCFC permite que várias incidências radiográficas sejam obtidas a partir de uma única aquisição volumétrica, diminuindo a necessidade de solicitação de exames radiográficos adicionais(20,21). Assim, a TCFC encontra-se de acordo com o princípio ALARA (“*as low as reasonably achievable*”) e apresenta um custo-benefício importante para o paciente, tanto em termos de dose de radiação recebida quanto em relação à versatilidade do exame realizado(22,23). Porém, talvez seja importante considerar a mudança de conduta de ALARA para ALADA (“*as low as diagnostically acceptable*”), visto que estão sendo obtidas “imagens bonitas”, que geralmente demandam uma dose de radiação mais elevada, quando apenas uma imagem adequada para diagnóstico é necessária(24).

O exame por TCFC permite ao profissional uma excelente visualização das estruturas ósseas e dentomaxilofaciais, auxiliando nos planos de tratamento e possibilitando o acompanhamento dos resultados e da estabilidade dos diversos

tratamentos ao longo do tempo. Estudos vêm demonstrando a aplicabilidade e estabelecendo diretrizes para o uso da TCFC no diagnóstico e no planejamento de intervenções nas áreas de cirurgia, implantodontia, ortodontia, endodontia, odontopediatria, entre outros. O interesse para o diagnóstico ortodôntico e cirúrgico, e a avaliação das vias aéreas por meio de exames por imagem, tem ficado mais evidente na literatura(25–28).

Em pesquisa, especialmente em modelos animais e na indústria, é possível e bem estabelecida a utilização de equipamentos de microtomografia computadorizada (micro-CT), que permitem a aquisição de imagens com mais alta resolução, fornecendo maior qualidade de detalhes(29). Porém, esses equipamentos permitem a aquisição de imagens apenas de pequenas estruturas, constituindo uma limitação em situações que apresentem volumes maiores.

As imagens de tomografia computadorizada, obtidas em qualquer tipo de equipamento, apresentam como importante vantagem, a possibilidade de interação com os dados armazenados. Com o uso de *softwares* específicos e de acordo com protocolos de aquisição baseados nas necessidades individuais, esse volume digital pode ser transformado em imagens multiplanares: axiais, coronais e sagitais. Além disso, algumas ferramentas permitem a realização de medidas e a geração de imagens tridimensionais(30).

1.2 MEDIDA DE VOLUME EM EXAMES POR IMAGEM

Inúmeros trabalhos citam diferentes métodos de diagnóstico, como a TCFL, a TCFC, a micro-CT e a ressonância nuclear magnética para a mensuração de volume de estruturas anatômicas e patologias. O volume das vias aéreas tem sido utilizado na comparação de situações clínicas pré e pós-operatórias(31), relacionando sua variação à presença de alterações anatômicas(32,33) e à presença de fenda palatina(34,35). Quanto à mensuração de patologias, podemos citar a avaliação do volume de lesões periapicais e o acompamento da cicatrização óssea pós-tratamento(36,37). A avaliação do volume de fendas palatinas e do enxerto necessário para sua correção também tem sido realizada com exames de TCFC(38,39).

Ferramentas para avaliação de volume tem sido utilizadas para estimar a idade a partir do volume da câmara pulpar de molares permanentes, com finalidade forense(40). O emprego de tais ferramentas para o acompanhamento de possíveis

reabsorções dentárias pós-tratamento ortodôntico ou pós-trauma dentoalveolar tem sido observado em alguns trabalhos. A avaliação é realizada importando-se as imagens de TCFC para programas que possibilitam sua segmentação de forma automática ou manual, avaliando a variação de volume de um determinado elemento dentário(41).

Assim, a possibilidade de avaliação do volume através da TCFC tem também se tornado cada vez mais frequente. Porém, existe uma lacuna na literatura a respeito de pesquisas clínicas que possam analisar e quantificar os volumes em exames de TCFC em diferentes condições clínicas com segurança e exatidão. Sabe-se que a ressonância magnética e a TCFL são exames mais fidedignos para tecidos moles e possuem escalas de tons de cinza aplicáveis(42,43). Porém, sabe-se também que os custos e o tempo para realização desses exames são maiores se comparados a TCFC, além das altas doses de radiação aplicadas na TCFL(44).

Lenza et al. compararam medidas lineares obtidas em radiografias cefalométricas de perfil e TCFC. Avaliando imagens de TCFC pelo método da segmentação (MIMICS 12.13 Materialise Interactive Medical Image Control System, Leuven, Belgium), concluíram que o volume das vias aéreas superiores, isoladamente, não representa adequadamente a morfologia das vias aéreas, sendo necessária uma análise completa, com medidas lineares, de área e de volume(45). Feng et al., utilizando o software Dolphin (Dolphin Imaging and Management Solutions, Chatsworth, CA, USA), observaram que a razão entre adenóide/nasofaringe (índice de adenoide e nasofaringe) obtida em radiografias cefalométricas de perfil, pode estimar o volume da nasofaringe, mas não de toda a extenção das vias aéreas superiores, em pacientes até 15 anos(46). A limitação desses estudos seria a falta de um padrão-ouro, pois são estudos clínicos.

Alguns estudos estão sendo realizados a fim de validar a TCFC, como um exame para medição de volume de vias aéreas(45–47), bem como de defeitos ósseos simulados em estudos *in vitro*(48,49), permitindo uma visualização das estruturas em três dimensões. Um estudo com fragmentos de mandíbula de porco demonstrou que o voxel interfere na acurácia de medidas de volume em imagens de TCFC(50).

Aboudara et al.(47) adquiriram imagens de TCFC de tubos plásticos com o interior preenchido por ar, com volume previamente determinado, simulando as vias aéreas. As imagens foram analisadas no software 3-D Doctor (Able Software, Lexington, Mass), pelo método da segmentação e foi observada excelente

confiabilidade nas medidas de volume, sendo estas reprodutíveis. Porém, uma limitação desse estudo é que a delimitação da via aérea simulada foi realizada em acrílico e não em tecidos moles. Entretanto, um recente estudo de Chen et al.(51), também avaliando vias aéreas, demonstrou diferença significativa ao comparar a medida de volume obtida em um *phantom* com as medidas de volume obtidas em três programas para medição de volume em imagens de TCFC(51).

Kasaven CP et al.(48) utilizaram o *software* MATLAB (The Mathworks Inc., R2009a, city, MA) para determinar o volume de imagens de TCFC de defeitos ósseos simulados em maxila, em imagens obtidas com o aparelho i-CAT (Imaging Sciences International, Hatfield, PA). Os resultados foram comparados com o volume obtido em imagens de micro-CT com a utilização do *software* Studio Max 2.2 (Volume Graphics, 2012, Heidelberg, Germany) e foi observado que as medidas de volume são similares. Resultado semelhante foi obtido por Ahlowalia et al.(52) que, simulando cavidades ósseas em osso bovino, concluíram que imagens de TCFC avaliadas com o *software* MicroView (GE Pre-clinical Imaging) para segmentação "*slice by slice*", demonstram boa acurácia na medida de volume, com resultados também comparáveis a imagens de micro-CT. Esses e outros estudos(40,53) consideram as imagens de micro-CT como padrão-ouro, porém sabe-se das limitações do uso desse método para volumes maiores.

Kamburoğlu K et al.(49) simularam defeitos ósseos na maxila e as imagens de TCFC foram importadas no software 3D Doctor (Able Software Corp., Lexington, MA, USA) para obtenção do volume pelo método da segmentação. A moldagem dos defeitos foi utilizada na técnica do deslocamento de água e pesada em uma balança (Scaltec SBC 21 balance - Denver Instrument, Bohemia, NY, USA). O volume médio obtido foi considerado o padrão de referência e comparado com medidas obtidas na TCFC e com *scanner* intraoral. Observaram que medidas de volume com *scanner* intraoral ficaram mais próximas do padrão ouro, mostrando maior acurácia do que medidas com TCFC(49). O método do deslocamento de água (Pincípio de Arquimedes) para obtenção do volume real também foi considerada padrão-ouro por estudos como os de Whyms et al.(54), de Rezende Barbosa et al.(38) e de Agbaje et al.(55)

Na avaliação de lesões simuladas por fresas em acrílico, a TCFC demonstra potencial em precisão, sendo um método não-invasivo e confiável para a detecção do tamanho e volume destas. Utilizando o software Analyze (Analyze Direct Inc., MN), a

acurácia da medida de volume foi superior com o método da segmentação manual quando comparado com a automática(56).

Esposito et al.(57), simulando lesões periapicais *in vitro* em mandíbula bovina, concluíram que a TCFC é uma boa técnica para estimativa de volume em lesões periapicais, quando comparada com o volume real obtido com moldagens de silicone, assim como para acompanhamento da saúde periodontal na região apical. Abdelhamid et al.(58) avaliaram a cicatrização de alvéolos, com e sem a utilização de biomateriais, seis meses após a exodontia, por meio da variação de volume da região em exames de TCFC, com a intenção de verificar o comportamento do tecido ósseo.

As avaliações de volume nos diversos estudos são realizadas de várias formas, usualmente sem padronização, e utilizando vários métodos. Na grande maioria das vezes, o volume é verificado importando-se as imagens DICOM (Digital Imaging and Communications in Medicine) em algum *software* disponível para a avaliação e que possua ferramentas que permitam a sua mensuração, seja por segmentação manual, automática ou automática com refinamento manual(40,41,54,59–65).

Em diversas situações clínicas, como nos casos em que o objetivo é avaliar a estabilidade do volume de enxerto(61,62), em levantamento de seio maxilar, ou para avaliar áreas prováveis doadoras para realização de enxerto autógeno(60,64), não é possível a obtenção de um padrão-ouro, sendo necessária a validação prévia de métodos para obtenção de volume a partir de imagens de TCFC. A revisão sistemática da literatura sobre este assunto, bem como a validação prévia de um método para a obtenção do volume real a partir de imagens de TCFC tem se tornado essencial para definir protocolos na radiologia odontológica.

Em condições clínicas reais, as estruturas ou lesões estão preenchidas ou revestidas por tecidos moles, o que pode interferir na aquisição e/ou medição nas imagens tomográficas. Assim, justifica-se a realização de um estudo para verificar a acurácia da medição do volume em imagens de TCFC, adquiridas em diversos aparelhos e protocolos, em situações simuladas *in vitro* e avaliadas em diferentes softwares (Anexo A).

2 OBJETIVOS

2.1 OBJETIVO GERAL

O objetivo geral do presente estudo é revisar sistematicamente a literatura e avaliar a acurácia de imagens tomográficas para a mensuração de volume em simulações de diferentes situações clínicas e patológicas, comparando protocolos de aquisição e *softwares*.

2.2 OBJETIVOS ESPECÍFICOS

Artigo 1

1. Realizar revisão sistemática da literatura sobre acurácia de medidas de volume em imagens de tomografia computadorizada.

Artigo 2

1. Comparar o volume encontrado nas imagens tomográficas dos corpos de prova confeccionados a partir de osso bovino, preenchidos com ar, água, propilenoglicol e tutano com o método de deslocamento de água para obtenção de medida física (padrão-ouro);
2. Comparar o volume encontrado nos corpos de prova quanto aos tomógrafos, protocolos para aquisição das imagens tomográficas e softwares para obtenção de volume;

3 ARTIGO 1

Are volume measurements in computerized tomography images accurate? Results from a systematic review

Formatado para ***Dentomaxillofacial Radiology***

Are volume measurements in computerized tomography images accurate? Results from a systematic review

Abstract

Objectives: To systematically review the literature on volumetric measurements, using computed tomography images, in diverse simulated clinical conditions to verify its accuracy when compared to a gold standard.
Methods: Two researchers read title and abstract of all studies. Selected studies had full text read to confirm fitting all criteria. A third researcher was called to solve disagreement. Inclusion and exclusion criteria were observed during all selection phases. A systematic search of the literature was conducted on May 29, 2019 in PubMed, Lilacs, Embase and Scopus. Medical Subject Headings (MeSH) terms and free keywords were chosen in PubMed and search was conducted using a combination of controlled vocabulary and free text terms as airway, paranasal sinuses, lesions, x-ray computed tomography, multidetector computed tomography, cone-beam computed tomography and x-ray microtomography. Reference lists of selected studies were also manually searched. QUAMAS tool (Quality Assessment of Measurement Accuracy Studies) was used to assess risk of bias of selected studies.
Results: After duplicates were excluded, 3172 studies had title and abstract read and 119 articles were selected for full text evaluation. Three articles were found by screening reference lists of selected studies. Fifty one selected studies were included and had data extracted. Fourteen studies were considered of low quality and 37 of high quality. Considering the high quality studies, 28 stated that volume measurements were accurate.
Conclusion: Evidence suggest that volume measurements in computed tomography images are accurate.

Keywords: Systematic review. Dimensional Measurement Accuracy. Multidetector Computed Tomography. Cone-Beam Computed Tomography.

INTRODUCTION

Since its development in the 1970s, computed tomography (CT) has become an essential tool for health diagnosis and treatment planning. By generating detailed anatomical image, the technology can improve diagnoses, limit unneeded medical procedures, and enhance treatment.[1] There are different types of CT devices/acquisitions with different characteristics. The multislice CT (MSCT) consists of a large number of detector elements in a single row across the irradiated slice to intercept the x-ray fan beam.[2] Cone-beam computed tomography (CBCT) is acquired by using a divergent pyramidal- or cone-shaped source of ionizing radiation directed through the middle of the area of interest onto an X-ray detector on the opposite side.[3] The need for higher resolution imaging for smaller specimens led to the first microfocus CT (micro-CT) scanners being developed in the 1980s; micro-CT scanners work similarly to CBCT scanners, and it is largest used in animal and industrial imaging diagnosis since has important limitations to use in clinical practice.[4]

In dentistry, CBCT is a precise imaging modality, offering better conditions for hard tissue visualization, multiplanar reconstruction on a 1:1 scale and with a considerably lower radiation dose when compared to MSCT. Mainly due to its advantages in lower effective radiation dose, lower costs, and easy access, it has become useful in oral diagnosis. However, it is known that CT scanners (regardless of category) emit X rays that can damage DNA and produce irreparable biological effects.[1]

The dynamic evaluation of CT images is one of the factors that contribute to exam diagnosis. Among the available tools, volume calculation is often used for pre and post evaluation of diverse treatments. In dentistry, they include evaluation of graft stability[5,6] in maxillary sinus lift and evaluation of candidate donor sites in autogenous graft,[7,8] where it is essential to produce an accurate measure of volume. Likewise, it is impossible to obtain gold standard, thus it is essential to have a validated method to supply volume information in these circumstances. However, there is a lack of consensus in the literature regarding the method (related to the CT category and protocol, as well as the type of segmentation) that produce the most accurate volumetric measures. Volume studies have been conducted with several designs, without standardization and using different measuring methods. Most of them evaluate volume by importing digital imaging and communications in medicine (DICOM) images

into available software, with specific tools that allow obtaining volumes, by manual or automated segmentation or automated refined by manual segmentation (semi-automated).[5–14]

The purpose of this study was to systematically review the literature on volumetric measurements, using computed tomography images, in different simulated clinical conditions to verify if these measures are accurate when compared to a gold standard.

METHODS

This systematic review was written according to the Preferred Reporting Items for a Systematic Review and Meta-Analysis of Diagnostic Test Accuracy Studies (The PRISMA-DTA Statement).[15]

Focused population, index test, reference standard, outcomes question

The research question of this systematic review was: “Are volume measures estimated in computed tomography (CT), cone-beam computed tomography (CBCT) and microcomputed tomography (micro-CT) accurate?”

In order to minimize the risk of missing relevant studies, searches were designed to be highly sensitive, although this resulted in low precision.[16] Therefore, as physical measurements are not always considered as a reference standard, search was conducted without this item.

Search strategy

A systematic search of the literature concerning volume measurements in CT, CBCT and micro-CT was conducted on May 29, 2019, with no publication year or language restriction. Databases searched were: PubMed, Lilacs, Embase and Scopus. Medical Subject Headings (MeSH) terms and free keywords were chosen in PubMed, based on previous studies conducted on the subject matter and search was conducted using a combination of controlled vocabulary and free text terms as airway, paranasal sinuses, lesions, x-ray computed tomography, multidetector computed tomography, cone-beam computed tomography and x-ray microtomography. The complete search is available in Appendix A. The same terms were used in Scopus and as a starting point to determine the keywords in the other two databases (Appendix B and C).

Reference lists of selected studies were also manually searched, looking for potentially missing articles.

Study selection and data extraction

Two researchers (AMW and JCT), independently, evaluated all studies. Initially, studies obtained from electronic databases had title and abstract screened. The studies selected in this phase were kept, even if they were identified by only one researcher. Selected studies had full text read to confirm fitting all criteria. In this step, a third researcher (MBV) was called whenever there was any disagreement about inclusion.

The following inclusion criteria should be observed during all selection phases: (a) *in vitro* or with part of the methodology *in vitro* full text studies, showing physical volume measurement as a gold standard; (b) all studies must have images acquired in computed tomography equipment (CT, CBCT or MCT); (c) volume measurements obtained in computed tomography exams. The exclusion criteria: (a) studies that did not compare physical volume with volume measured in computed tomography; (b) letters and personal opinion, case reports and reviews; (c) studies with no full text available.

Both reviewers performed the data extraction of selected studies. For each study the following items were collected: title, publication year, journal, supporting sources, authors, country, publication language, objective, study type, gold standard, sample calculation, sample size, number of researchers, exam and equipment type, acquisition protocol, volume software, evaluated structure, statistical test, results and conclusion (Appendix D – digital file).

Assessment of risk of bias and quality of evidence of the included studies

QUADAS 2 (Quality Assessment Of Diagnostic Accuracy Studies)[17] is the most used tool to access study quality in diagnostic accuracy systematic reviews. However, other systematic reviews[18–22] that also used measurement accuracy, evaluated study quality with another tool, adjusting the items to fit appropriately. In this systematic review, the tool was adjusted (Table 1) based on one study[23] that called this tool QUAMAS (Quality Assessment of Measurement Accuracy Studies). QUAMAS tool is based on three basic parameters: study design, study measurements and data

analysis. Each item was scored 1 = yes, 0 = no or 0,5= unclear, incomplete information or considered not enough. The maximum score of a study was 11. The risk of bias was categorized as *high* when the study reached under 7 points and *low* when the study scored 7 or more. The cut point was 63.63%, similar to Zimmerman[22] which established 65%.

Table 1: Bias risk assessment of studies of diagnostic performance included in systematic reviews (QUAMAS) tool, modified from Li et al 2019.[23]

QUAMAS (Quality Assessment of Measurement Accuracy Studies) tool modified from Li et al 2019			
Parameter of evaluation			Score
Study design (3*)	A	Objective clearly formulated (*)	1
	B	Sample size: considered adequate (*)	1
	C	Sample size: estimated before data collection (*)	1
Study measurement (3*)	D	Physical model measurement method is appropriate (*)	1
	E	Adequate examiners and independent measurement (*)	1
	F	Segmentation method conducted in an adequate way (*)	1
Statistical analysis (5*)	G	Statistical analysis is appropriate for data (*)	1
	H	Reliability: intra-examiner (*) and inter-examiner (*)	2
	I	Statistical significance level: P value (*) and confidence intervals (*)	2
Total			11

Evaluation checklist for the included studies. One award (*) indicates that the study fulfilled the concern

RESULTS

Study selection

Search in PubMed retrieved 479 studies, in Lilacs 754, in Embase 588 and in Scopus 1980. From 3801 studies identified, 629 were duplicates and were excluded. A total of 3172 studies had title and abstract read by two independent researchers. Databases search resulted in 119 articles selected for full text evaluation, even if only one researcher had selected it. Other three articles were found by screening reference lists of selected studies. After full text reading, 51 studies were selected for data extraction. PRISMA flow diagram[24] represents selection process and reports exclusion reasons for 71 studies (Figure 1).

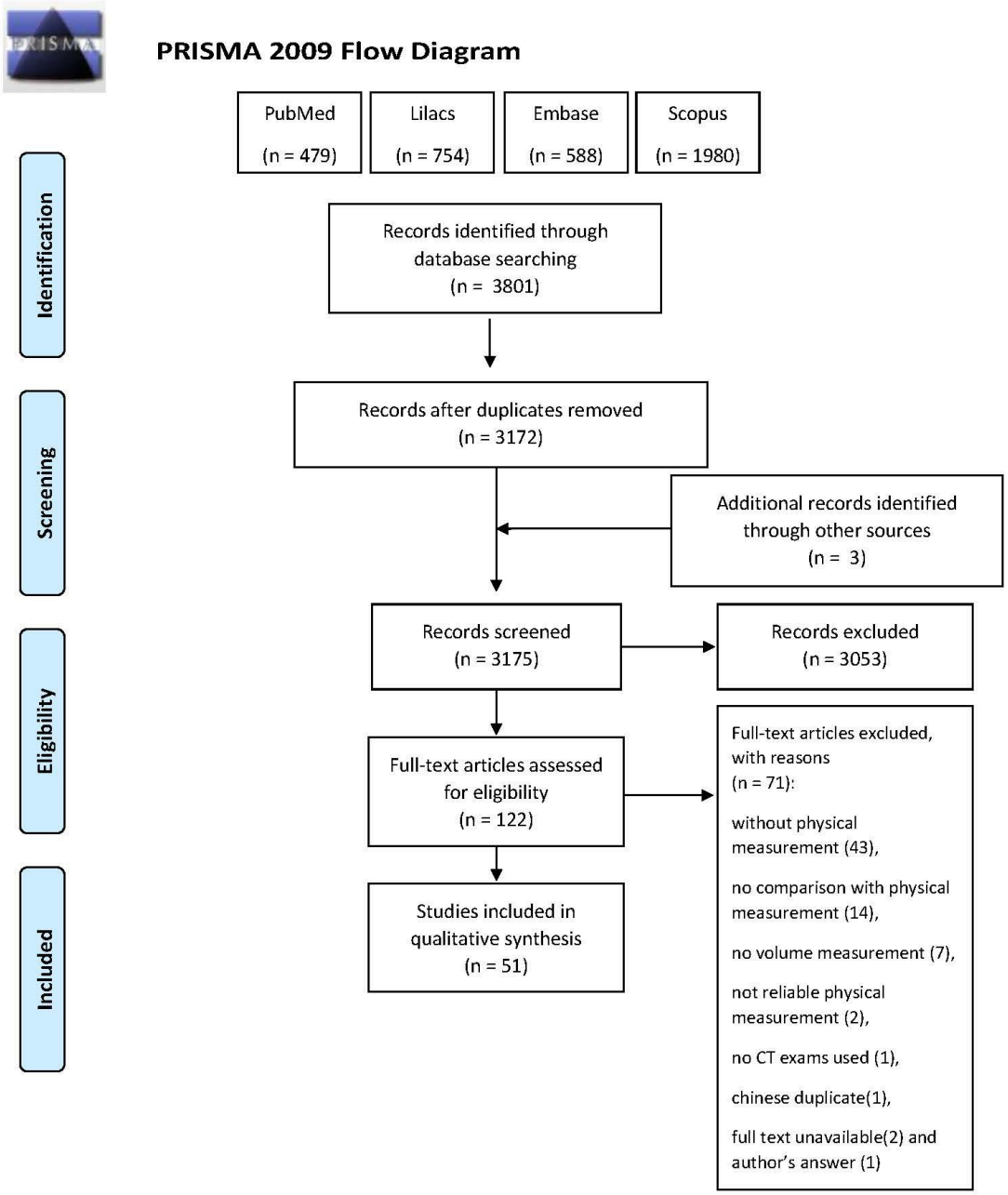

Figure 1: Flow diagram with the information through the phases of study selection according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.

Characteristics of the included studies

Selected studies were published between 2000 and 2019. Four articles were not published in English: one was in Spanish,[25] one in Chinese,[26] one in Germany[27] and one in Korean.[28] Different structures were measured and some studies evaluated more than one structure type: 15 studies used empty cavities,[25,29–42] 11 used simulated pulmonary nodules,[26,27,43–51] ten used soft tissues or simulating soft tissues materials,[28,52–60] seven used hard tissues[11,31,61–65] and 12 used other structures.[39,42,53,66–74] Regarding exam type, 32 studies used CT,[11,25–29,33,37,43–60,63,68–72] 16 CBCT,[30–32,34–36,39–42,61,62,64–67] one micro-CT,[74] one used both CT and CBCT[73] and one used both CBCT and micro-CT.[38] In order to simplify and unify terms, multislice computed tomography (MSCT), multidetector computed tomography (MDCT), multislice spiral computed tomography, volumetric computed tomography (VCT) and multidetector computed tomography angiography (CTA), were all designated as CT.

Archimedes' principle of water displacement technique, was the method used in 28 studies[11,25,27,32–34,36–39,41,44,45,52,55,58–66,68,69,71,73] to determine physical volume of evaluated structures and considered as the gold standard. In 16 studies,[26,28,29,35,42,46,47,49–51,53,56,57,67,70,72] structures had previously known volumes. Volume was obtained by weighting the material in an analytical balance and using its density in four studies.[30,31,40,48] One study used a digital caliper to determine the dimensions and to calculate volume.[43] Another study used gravimetric method[74] and just one study[54] did not describe the method to obtain actual volume.

The most common way to measure volume in computed tomography images was by using some kind of volume tool available in medical or health software. Thirty-seven different software were used. Analyze (AnalyzeDirect Inc., Overland Park, KS, EUA) was the most commonly used, being present in five studies.[11,35,63,67,71] It was followed by Dolphin Imaging® Systems (Dolphin, Inc., Chatsworth, Calif.)[30,39,42,65] and Vitrea (Vital Images Inc., Plymouth, MN, USA),[52,59,69,73] both being used in four studies. Most of the studies used only one software to measure volume. One study compared volumes obtained with five different software,[59] one compared four[34] and two compared two software.[66,71] In these studies, the software measurements were evaluated by means of accuracy. Two studies[25,37] used Cavalieri's principle and did not use any software to measure volume. Cavalieri's principle was also used in another two studies. One associated this method with ImageJ software (National Institute of

Health, Bethesda, USA)[62] and the other with manual segmentation comparing to an automated segmentation tool.[53]

Volume measurement method or segmentation type, despite the presence of method description, were not clearly stated in 18 studies.[27,29–31,33,39,40,42,44,52,54,55,58,63,66,69,71,72] Thirteen studies measured volume by automated segmentation,[26,28,32,35,41,43,45,46,49,51,65,68,73,74] six by semi-automated,[36,47,56,57,61,70] four by manual segmentation,[38,60,64,67] one by automated segmentation with manual correction,[41] two by both manual and semi-automated[48,59] and two by both manual and automated.[11,50] One study used two manual segmentation software and other two software with not specific method.[34]

Risk of bias and Quality of evidence of the included studies

Risk of bias in selected studies ranged from low to high. According to QUAMAS, the tool used to evaluate quality and risk of bias, 14 studies were considered of low quality,[26–29,31,33,44–46,48,49,55,63,71] scoring less than 7, and 37 of high quality,[11,25,30,32,34–43,47,50–54,56–62,64–70,72–74] scoring 7 or more. Limitations related to previous sample size estimation, examiners and lack of intra or inter-examiner assessment were the major problems identified. The overview of the quality analysis for included studies is provided in Table 2. High quality included studies and their main characteristics are available in Table 3.

TABLE 2. Quality assessment of the included studies using the QUAMAS (Quality Assessment of Measurement Accuracy Studies) tool. Evaluation scores of included studies (n=51).

Studies	Study design			Study measurement			Statistical analysis			
	A	B	C	D	E	F	G	H	I	total
Pinsky HM (2006)[35]	1	1	1	1	0,5	1	1	2	2	10,5
Bolte H (2007)[47]	1	1	0	1	1	1	1	2	2	10
MARTEN K (2009)[51]	1	1	0	1	1	1	1	2	2	10
Liu Y (2010)[61]	1	1	0	1	1	1	1	2	2	10
Esposito SA (2013)[40]	1	1	0	1	1	1	1	2	2	10
Kirmeier R (2011)[70]	0,5	0,5	1	1	1	1	1	2	2	10
Cavalcanti MGP (2000)[52]	1	0,5	0	1	1	1	1	2	2	9,5
Albuquerque MAP (2011)[69]	1	0,5	0	1	1	1	1	2	2	9,5
Ahlowalia MS (2013)[38]	1	0,5	0	1	1	1	1	2	2	9,5
Amirlak B (2013)[39]	1	0,5	0	1	1	1	1	2	2	9,5
Lubner MG (2014)[59]	1	0,5	0	1	1	1	1	2	2	9,5
SACCUCCI M (2015)[42]	1	0,5	0	1	1	1	1	2	2	9,5
Sang YH (2016)[64]	1	1	0,5	1	1	1	1	1	2	9,5
Garcia-Sanz V (2017)[65]	1	0,5	0	1	1	1	1	2	2	9,5
Dudeck O (2005)[53]	1	1	0	1	1	1	1	1	2	9
Osaki TH (2013)[58]	0,5	0,5	0	1	1	1	1	2	2	9
Elashiry M (2018)[67]	1	1	0	1	1	1	1	1	2	9
Dudeck O (2006)[68]	1	0,5	0	1	1	1	1	1	2	8,5
Albuquerque MAP (2011.1)[73]	1	0,5	0	1	1	1	1	2	1	8,5
Bayram M (2012)[62]	1	0,5	0	1	1	1	1	1	2	8,5
Liang H-Y (2014)[41]	1	1	0	1	0,5	1	1	1	2	8,5
Walde TA (2005)[54]	1	1	0	1	1	1	1	0	2	8
Da Silveira PF (2015)[30]	1	0,5	0	1	0,5	1	1	1	2	8
de Rezende Barbosa GL (2016)[66]	1	0,5	0	1	0,5	1	1	1	2	8
Sönmez G (2018)[34]	1	1	0	1	1	1	1	0	2	8
Coronado C (2010)[25]	1	1	0	1	0,5	1	1	0	2	7,5
Prionas ND (2010)[72]	1	1	0	1	0,5	1	1	0	2	7,5
Coronado C (2011)[37]	1	1	0	1	0,5	1	1	0	2	7,5
Fabel M (2011)[57]	1	1	0	1	0,5	1	1	0	2	7,5
Kamburoglu K (2015)[32]	1	0,5	0	1	1	1	1	0	2	7,5
Agbaje JO (2007)[36]	1	1	0	1	0,5	0,5	1	0	2	7
Way TW (2008)[50]	1	0,5	0	1	0,5	1	1	0	2	7
Keil S (2009)[56]	1	0,5	0	1	0,5	1	1	0	2	7
Linning E (2009)[43]	1	0,5	0	1	0,5	1	1	0	2	7
Whyms BJ (2013)[11]	1	0,5	0	1	0,5	1	1	0	2	7
Parrilli A (2016)[74]	1	0,5	0	1	0,5	1	1	0	2	7
Haverkamp K (2019)[60]	1	0,5	0	1	0,5	1	1	0	2	7
Bolte H (2007.1)[48]	0,5	1	0	1	0	1	1	0	2	6,5
Larici AR (2008)[49]	1	0,5	0	1	0	1	1	0	2	6,5
Divani AA (2011)[71]	1	0,5	0	1	0	1	1	0	2	6,5
Kim H (2013)[28]	1	0,5	0	1	0	1	1	0	2	6,5
Kobayashi Y (2017)[33]	1	0,5	0	1	0,5	1	0,5	1	1	6,5
Marten K (2004)[44]	0,5	1	0	1	0	0,5	1	0	2	6
Marten K (2004.1)[27]	1	1	0	1	0	1	1	0	1	6

TABLE 2. Quality assessment of the included studies using the QUAMAS (Quality Assessment of Measurement Accuracy Studies) tool. Evaluation scores of included studies (n=51).

Studies	Study design			Study measurement			Statistical analysis			
	A	B	C	D	E	F	G	H	I	total
Goo JM (2005)[45]	1	0,5	0	1	0,5	1	1	0	1	6
Kuhnigk J-M (2006)[46]	1	1	0	1	0	1	1	0	1	6
COTTER MM (2015)[63]	1	0,5	0	1	0	1	1	0	1	5,5
Luntz M (2001)[29]	1	0,5	0	1	0,5	1	0,5	0	0	4,5
Su D (2017)[26]	1	0,5	0	1	0	1	1	0	0	4,5
Sommer G (2007)[55]	1	0,5	0	1	0	0,5	1	0	0	4
Pinchi V (2015)[31]	1	0,5	0	0,5	0	1	1	0	0	4

TABLE 3. High quality included studies (n=37): evaluated structure, equipment type, volume measurement and accuracy.

Author (year)	Structure / density	equipment type	Software / volume measurement	Accuracy
Cavalcanti MGP (2000)[52]	simulated tumors in mandible	CT	Vitrea™ software NOT REPORTED	accurate
Dudeck O (2005)[53]	simulating intravenous contrast	CT	CAVALIERI METHOD with MANUAL segmentation AND Volume Tool; General Electric Medical Systems AUTOMATED SEGMENTATION	accurate
Walde TA (2005)[54]	simulating granuloma tissue	CT	Muscular-Skeleton Analysis Software, Osteolysis Measurement Module, Version 2.0 (Virtual Scopics, LCC, Rochester, NY) NOT REPORTED	accurate
Dudeck O (2006)[68]	simulated aneurysms (POLYMER)	CT A	3D software measurement tool for (Volume Tool; GE Medical Systems, Milwaukee, USA) AUTOMATED	accurate
Pinsky HM (2006)[35]	simulated defects / cavity; air	CBCT	Analyze (Analyze Direct Inc., MN) AUTOMATED SEGMENTATION	accurate

TABLE 3. High quality included studies (n=37): evaluated structure, equipment type, volume measurement and accuracy.

Author (year)	Structure / density	equipment type	Software / volume measurement	Accuracy
Agbaje JO (2007)[36]	teeth socket / cavity; air	CBCT	Livewires (Institute of Computing, State University of Campinas, Brazil) SEMI-AUTOMATED segmentation	accurate
Bolte H (2007)[47]	simulated pulmonary nodules	CT	LungCARE_, CT 2006A, Siemens, Erlangen, Germany SEMI-AUTOMATED SEGMENTATION	accurate
Way TW (2008)[50]	simullated pulmonary nodules	CT	AUTOMATED SEGMENTATION and MANUAL SEGMENTATION	Accuracy is better with automated segmentation, thiner slices and large structure
Keil S (2009)[56]	hepatic lesions / simulating soft tissue	CT	a tool SyngoOncology (Siemens Medical Solutions, Forchheim, Germany)SEMI-AUTOMATED SEGMENTATION	accurate
Linning E (2009)[43]	simulated GGO nodules	CT	Lung VCAR; GE Healthcare AUTOMATED SEGMENTATION	accurate
MARTEN K (2009)[51]	soft-tissue-equivalent material	CT	LungCare, Somaris 5 VB10 AW.4, (Siemens Medical Solutions, Forchheim, Germany) AUTOMATED SEGMENTATION	not reported
Coronado C (2010)[25]	orbit / cavity; air	CT	Cavalieri's principle	accurate
Liu Y (2010)[61]	tooth / hard tissue	CBCT	Amira 4.0 (Visage Imaging Inc, Carlsbad, Calif) semiautomated with manual intervention.	seems to be accurate

TABLE 3. High quality included studies (n=37): evaluated structure, equipment type, volume measurement and accuracy.

Author (year)	Structure / density	equipment type	Software / volume measurement	Accuracy
Prionas ND (2010)[72]	injection-molded polymethylmethacrylate spheres	CT	ImageJ version 1.40 (U.S. National Institutes of Health, Bethesda, MD) and segmentation code written in C ++ (Visual Studio 2005, Microsoft Corporation, Redmond, Washington) NOT REPORTED	accurate for large volumes with thinner slices
Albuquerque MAP (2011)[69]	bone defect (cleft) / water and wax	MSCT	Vitrea, version 3.6 (Vital Images Inc., Plymouth, MN, USA) NOT REPORTED	accurate
Albuquerque MAP (2011.1)[73]	bone defect (cleft) / wax	MSCT e CBCT	Vitrea software 3.8.1 (Vital Images, Plymouth, MN, USA) AUTOMATED SEGMENTATION	accurate
Coronado C (2011)[37]	seio maxilar / cavity; air	CT	Cavalieri's principle	accurate
Fabel M (2011)[57]	artificial lymph nodes	CT	Oncology Software (Siemens Healthcare, Forchheim, Germany) SEMI-AUTOMATED SEGMENTATION	accurate
Kirmeier R (2011)[70]	simulated maxillary sinuses mimicked by moulding material filled with a radiopaque liquid.	CT	a tool of Somaris1 Sienet Magic View 10001, VB32B, Siemens AG, Medical Solutions, Erlangen, AlemanhaSEMI-AUTOMATED SEGMENTATION	accurate
Bayram M (2012)[62]	the condylar head and neck / bone	CBCT	CAVALIERI + IMAGEJ	accurate
Ahlowalia MS (2013)[38]	simulated periapical lesions /cavity; air	CBCT e microCT	software MicroView® (GE Pre-clinical Imaging) MANUAL SEGMENTATION	accurate

TABLE 3. High quality included studies (n=37): evaluated structure, equipment type, volume measurement and accuracy.

Author (year)	Structure / density	equipment type	Software / volume measurement	Accuracy
Amirlak B (2013)[39]	alveolar defects (cleft) / cavity; air and Polyvinyl siloxane	CBCT	Accurex, In Vivo (Anatomage, Inc., San Jose, Calif.) Dolphin Imaging Systems, (Dolphin, Inc., Chatsworth, Calif.) NOT REPORTED	accurate
Esposito SA (2013)[40]	periapical region bone defect / cavity; air	CBCT	new volume measurement tool NOT REPORTED	accurate
Osaki TH (2013)[58]	orbit / soft tissue	CT	Voxar 3D software (Barco, Edinburgh, Scotland) NOT REPORTED	not accurate
Whyms BJ (2013)[11]	mandible and prism / bone	CT	Tool of Analyze® MANUAL AND AUTOMATED SEGMENTATION	accurate, depending on slice thickness
Liang H-Y (2014)[41]	simulated periapical lesions /cavity; air	CBCT	Amira 5.4.3 (Visage Imaging GmbH, Berlin, Germany) AUTOMATED SEGMENTATION, WITH MANUAL CORRECTION	accurate
Lubner MG (2014)[59]	simulated nodules	CT	Ziosoft v2.0.0.2 (Redwood City, CA) / MANUAL SEGMENTATION,GE Medical v4.4 (Waukesha, WI) / MANUAL SEGMENTATION,Philips EBW v4.5.2 (Best, The Netherlands) /SEMI-AUTOMATED SEGMENTATION, ViatronixV3DExplorer v3.2.3(Stony Brook, NY) / MANUAL SEGMENTATION Vitrea/Vital Images v5.1 (Minnetonka,MN) /MANUAL SEGMENTATION	accuracy depends on various factors

TABLE 3. High quality included studies (n=37): evaluated structure, equipment type, volume measurement and accuracy.

Author (year)	Structure / density	equipment type	Software / volume measurement	Accuracy
Da Silveira PF (2015)[30]	root resorption / cavity; air	CBCT	Dolphin 3D software (Dolphin Imaging and Management Solutions, Chatsworth, CA, USA) NOT REPORTED	accurate depending on voxel size
Kamburoglu K (2015)[32]	cavity; air	CBCT	3D Doctor (Able Software Corp., Lexington, MA, USA) AUTOMATED SEGMENTATION	accurate
SACCUCCI M (2015)[42]	cavity; air and alginate	CBCT	Dolphin Imaging software (Dolphin Imaging and Management solution, USA) NOT REPORTED	accurate
de Rezende Barbosa GL (2016)[66]	Alveolar defect /utility wax	CBCT	inVivo software (Anatomage, San Jose, CA); Software Mimics® (v. 16.0, Materialize Medical, Leuven, Bélgica) NOT REPORTED	accurate for 2 methods
Parrilli A (2016)[74]	An alumina (Biolox® Forte) femoral head (Ø = 28 mm) ceramic femoral head prostheses	micro CT	CTAn version 1.13.11.0 (Bruker, Kontich, Belgium) AUTOMATED SEGMENTATION	accurate
Sang YH (2016)[64]	tooth / hard tissue	CBCT	Materialise Mimics 18.0 (Mimics Innovation Suite18.0, Materialise Dental, Leuven, Belgium)MANUAL SEGMENTATION	accurate
Garcia-Sanz V (2017)[65]	condile / bone	CBCT	Dolphin Imaging® (Dolphin Imaging and Management Solutions, Chatsworth, CA, USA) AUTOMATED SEGMENTATION	accurate

TABLE 3. High quality included studies (n=37): evaluated structure, equipment type, volume measurement and accuracy.

Author (year)		Structure / density	equipment type	Software / volume measurement	Accuracy
Elashiry (2018)[67]	M	periodontal pocket / Radiopaque micro-particle filler	CBCT	Analyze 110 imaging (Analyze Direct, Inc., Overland Park, KS, USA) MANUAL SEGMENTATION	accurate
Sönmez (2018)[34]	G	cavity; air	CBCT	1) Dedicated Planmeca Romexis Viewer (Planmeca Oy, Helsinki, Finland); NOT REPORTED 2) 3D- DOCTOR (Able SoftwareCorp., Lexington, MA); MANUAL SEGMENTATION and automated calculation of the total volume 3) Open source application: ITK-SNAP version 3.4.0 (http://itksnap.org); and - MANUALLY SEGMENTED 4) Osirix (Pixmeo SARL, Bernex, Switzerland). NOT REPORTED	accurate
Haverkamp (2019)[60]	K	prostate /soft tissue	CT	Amira MANUAL segmentation	accurate

Discussion

Volume analysis has greatly increased mainly due to widespread use of CT scans. Particularly in Dentistry, the CBCT is used to evaluate airway,[20,75] implant sites,[23] pulp cavities,[9] tooth volume,[10] paranasal sinuses,[42] beyond the indications already mentioned graft stability[5] and donor sites.[7,8] Despite the previously mentioned advantages of CBCT, it is already expected that MSCT present better tissue rendering due to the device and acquisition characteristics. In this sense, the most important limitation of CBCT imaging is the low contrast resolution.[76] Because of its high-resolution scanning, micro-CT is sometimes considered as a gold standard in volume measurements.[9,77–79]

This systematic review was conducted in order to establish the accuracy of volume measurements in CT, CBCT and micro-CT. The search strategy was designed to retrieve all studies comparing these volume values with a physical gold standard, regardless of the exam category, the structure measured, or the volume measurement method. The analysis of 51 included studies showed that only three had sample size estimated before data collection.[35,64,70] However, one of them did not use the indicated number of specimens.[70]

Regarding statistical analysis, 23 studies[30,33,52,53,58,59,61,62,64–67,35,69,70,73,38–42,47,51] used some kind of reproducibility test to assess reliability and just one was rated under 7. However, only 14[38,39,65,69,70,73,40,42,47,51,52,58,59,61] used both intra and inter-examiner evaluation, obtaining at least 8.5 points. To evaluate accuracy, 19 studies[11,26,51,52,58,59,64,66,69,72,74,28,30,34,41–43,48,50] used ANOVA and seven[25,27,43,47,56,57,70] used percentage error or deviation from physical volume evaluation. The other studies used other types of analyses such as T test and regression model. Some studies conducted additional evaluation, using concordance correlation coefficient and Bland Altman plots.

Goo,[45] Su[26] and Way,[50] evaluating simulated pulmonary nodules, observed that accuracy is dependent of nodule size, obtaining more accurate measurements for larger volumes. Kim[28] and Prionas[72] obtained similar conclusions using simulated tumors. This could be a relevant information, since it states that smaller volume measurements are less accurate. However, three of these studies[26,28,45] were rated under 7.

Considering only the high quality studies (Table 3), 13 studies[25,37,68–70,43,47,52–54,56,57,60] out of 19 using CT found accurate volume measurements. One CT study observed that volume measurements accuracy depends on slice thickness,[11] two observed more accurate measurements in large volumes with thinner slices,[50,72] one study did not state about accuracy,[51] and only one found not accurate measurements.[58] Accurate measurements were also obtained in one study using micro-CT,[74] one using micro-CT and CBCT[38] and another using CT and CBCT.[73]

Twelve studies out of 15 using CBCT as the only image exam stated that measuring volume, compared to gold standard, was accurate. Eight of them evaluated empty cavities[32,34–36,39–42] and four, hard tissues or similar density structures.[62,64,65,67] One study[30] measured volume in simulated internal root resorption and concluded that accuracy depends on voxel size, as measurements obtained with 0.076 and 0.300

were accurate and with 0.200 were not. Another one found accurate results for Mimics® software (v. 16.0, Materialise Medical, Leuven, Belgium) and for a method based in the area using inVivo software (Anatomage, San Jose, CA), but not for the method based in linear measurements to estimate volume with the same software.[66] Additionally, five studies, one using CBCT[35] and four using CT,[51,53,60,70] reported a tendency to underestimate volume. Despite obtaining accurate measurements, with no statistically significant differences, Amirlak[39] observed that simulated bone graft tends to underestimate volume measurements and bone defect tends to overestimate when compared to gold standard. That is an important observation, since different contents could demonstrate diverse behavior regarding volume measurements. A possible reason for this, could be the difficulty in segmenting structures with similar grey values.

Liu[61], in a clinical study to validate volume of teeth with extraction indication for orthodontic reasons, reported that CBCT measurements seemed to be accurate. Authors did not affirm this due to the lack of requirements for accuracy of volumetric determinations. Indeed, it was observed that there is no consensus on the acceptable range for a measurement to be considered accurate and most of the studies does not explain the adopted parameters. Whyms[11] assessed accuracy comparing digital volume measurements to gold standard by calculating the average absolute relative error (ARE). In this study, an ARE 0.05, which reflects the average difference of less than 5% between anatomical and digital measurement, was considered to be acceptably accurate.

Automated, semi-automated and manual segmentation were used regardless exam type. Using CT, Way[50] comments that for simulated nodules (an area where several studies were found), the automated segmentation would be better. Dudeck,[53] in an *in vitro* intracranial aneurysms study, also recommends automated segmentation due to its accuracy, precision and time-efficiency. Finally, Lubner[59] considers that accuracy depends on several factors in addition to segmentation type.

According to Whiting,[80] to avoid misidentification of relevant studies, systematic reviews of test accuracy should search a range of databases. This is an extremely positive point in the present study and the reason why this review search was conducted on four databases. It was considered not adequate to perform a meta-analysis due to great data variability regarding machines, acquisition protocols, and measurement software or structures density. Even studies using the same exam type used different acquisition protocols or measured volume in a diverse way. Additionally,

some studies used gold standards with previously known volume or did not have average or standard deviation for this measure.[28,35,46,49–51,53,57,70]

Regardless of quality classification and type of image exam, 33 studies[25,27,39–43,47,49,52–54,29,55–57,60,62,64,65,67–69,32,70,73,74,33–38] considered volume measurements accurate. Only two studies found not accurate measurements, one was considered of high quality[58] and the other of poor quality.[31] Considering the 37 studies scored as high quality, regardless exam type or measuring method 28 stated that volume measurements were accurate.[25,32,42,43,47,52–54,56,57,60,62,34,64,65,67–70,73,74,35–41] However, some other studies obtained accurate measurements only in certain situations, such as: three studies stated that volume measurements are more accurate for thinner slices,[11,50,72] and two[50,72] of them added that measuring large volumes are even more accurate. One study observed that accuracy depends on voxel size,[30] two that it depends on segmentation type or measurement method,[50,66] and three simply did not stated whether the measurements were accurate or not.[51,59,61] In conclusion, despite the type of computed tomography, evidences suggest that volume measurements in DICOM images are accurate.

REFERENCES

1. Schmidt CW. CT scans: balancing health risks and medical benefits. Vol. 120, Environmental health perspectives. United States; 2012. p. A118-21.
2. Goldman LW. Principles of CT: multislice CT. J Nucl Med Technol. 2008 Jun;36(2):56–7.
3. Scarfe WC, Farman AG. What is cone-beam CT and how does it work? Dent Clin North Am. 2008 Oct;52(4):707–30, v.
4. Hutchinson JC, Shelmerdine SC, Simcock IC, Sebire NJ, Arthurs OJ. Early clinical applications for imaging at microscopic detail: microfocus computed tomography (micro-CT). Br J Radiol. 2017 Jul;90(1075):20170113.
5. Ohe JY, Kim GT, Lee JW, Al Nawas B, Jung J, Kwon YD. Volume stability of hydroxyapatite and β-tricalcium phosphate biphasic bone graft material in maxillary sinus floor elevation: A radiographic study using 3D cone beam computed tomography. Clin Oral Implants Res. 2016;27(3):348–53.
6. Berberi A, Bouserhal L, Nader N, Assaf RB, Nassif NB, Bouserhal J, et al. Evaluation of Three-Dimensional Volumetric Changes After Sinus Floor Augmentation with Mineralized Cortical Bone Allograft. J Maxillofac Oral Surg. 2015;14(3):624–9.
7. Bernades-Mayordomo R, Guijarro-Martínez R, Hernández-Alfaro F. Volumetric CBCT analysis of the palatine process of the anterior maxilla: A potential source for bone grafts. Int J Oral Maxillofac Surg [Internet]. 2013 Mar [cited 2019 Jul 15];42(3):406–10. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23062715
8. Altug HA, Coskun AT, Kamburoglu K, Zerener T, Gulen O, Sencimen M, et al. Volumetric Evaluation of Safe Zone for Bone Harvesting from Symphysis Region by Using Cone Beam Computed Tomography. Implant Dent. 2016;25(6):758–61.
9. Ge Z pu, Ma R han, Li G, Zhang J zong, Ma X chen. Age estimation based on pulp chamber volume of first molars from cone-beam computed tomography images. Forensic Sci Int. 2015;253:133.e1-133.e7.
10. Forst D, Nijjar S, Flores-Mir C, Carey J, Secanell M, Lagravere M. Comparison of in vivo 3D cone-beam computed tomography tooth volume measurement protocols. Prog Orthod. 2014;15:69.

11. Whyms BJ, Vorperian HK, Gentry LR, Schimek EM, Bersu ET, Chung MK, et al. The effect of computed tomographic scanner parameters and 3-dimensional volume rendering techniques on the accuracy of linear, angular, and volumetric measurements of the mandible. Oral Surg Oral Med Oral Pathol Oral Radiol [Internet]. 2013;115(5):682–91. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L368780625
12. Saccucci M, Polimeni A, Festa F, Tecco S. Do skeletal cephalometric characteristics correlate with condylar volume, surface and shape? A 3D analysis. Head Face Med. 2012;8(1).
13. Klein GBG, Curvello VP, Dutra RA, Simeão SP, Santos PL, Gulinelli JL, et al. Bone volume changes after sinus floor augmentation with heterogenous graft. Int J Oral Maxillofac Implants [Internet]. 2016;31(3):665–71. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L615817741
14. Goulart DR, Muñoz P, Cantín López MG, de Moraes M, Olate S. Comparative Evaluation of Condylar Volume Between Patients With Unilateral Condylar Hyperplasia and Class III Dentofacial Deformity. J Oral Maxillofac Surg. 2017;75(1):180–8.
15. McInnes MDF, Moher D, Thombs BD, McGrath TA, Bossuyt PM, Clifford T, et al. Preferred Reporting Items for a Systematic Review and Meta-analysis of Diagnostic Test Accuracy Studies: The PRISMA-DTA Statement. JAMA. 2018 Jan;319(4):388–96.
16. de Vet HCW, Eisinga A, Riphagen II, Aertgeerts B PD. Chapter 7: Searching for Studies. In: Cochrane Handbook for Systematic Reviews of Diagnostic Test Accuracy Version 04 [updated September 2008]. The Cochrane Collaboration; 2008.
17. Whiting PF, Rutjes AWS, Westwood ME, Mallett S, Deeks JJ, Reitsma JB, et al. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. Ann Intern Med. 2011 Oct;155(8):529–36.
18. Lagravere MO, Major PW, Flores-Mir C. Long-term skeletal changes with rapid maxillary expansion: a systematic review. Angle Orthod. 2005 Nov;75(6):1046–52.
19. Gordon JM, Rosenblatt M, Witmans M, Carey JP, Heo G, Major PW, et al. Rapid

palatal expansion effects on nasal airway dimensions as measured by acoustic rhinometry. A systematic review. Angle Orthod. 2009 Sep;79(5):1000–7.

20. Alsufyani NA, Flores-Mir C, Major PW. Three-dimensional segmentation of the upper airway using cone beam CT: a systematic review. Dentomaxillofac Radiol. 2012 May;41(4):276–84.
21. van Vlijmen OJC, Kuijpers MAR, Berge SJ, Schols JGJH, Maal TJJ, Breuning H, et al. Evidence supporting the use of cone-beam computed tomography in orthodontics. J Am Dent Assoc. 2012 Mar;143(3):241–52.
22. Zimmerman JN, Lee J, Pliska BT. Reliability of upper pharyngeal airway assessment using dental CBCT: a systematic review. Eur J Orthod. 2017 Oct;39(5):489–96.
23. Li Y, Deng S, Mei L, Li J, Qi M, Su S, et al. Accuracy of alveolar bone height and thickness measurements in cone beam computed tomography: a systematic review and meta-analysis. Oral Surg Oral Med Oral Pathol Oral Radiol. 2019 May;
24. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009 Jul;6(7):e1000097.
25. Coronado G C, Arriagada C O, Zavando M D, del Sol C M, Suazo G I. Estimation of the orbital volume with ct images and Cavalieri's principle. Rev Chil Radiol. 2010;16(2):59–63.
26. Su D, Feng L, Jiang Y WY. Effect of scanning and reconstruction parameters on three dimensional volume and CT value measurement of pulmonary nodules: A phantom study. Chinese J Lung Cancer [Internet]. 2017;20(8):562–7. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L619279157
27. Marten K, Engelke C, Grabbe E, Rummeny EJ. Flat-panel detector-based computed tomography: Accuracy of experimental growth rate assessment in pulmonary nodules. RoFo Fortschritte auf dem Gebiet der Rontgenstrahlen und der Bildgeb Verfahren [Internet]. 2004;176(5):752–7. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-2642575985&doi=10.1055%2Fs-2004-813020&partnerID=40&md5=ef5e82e1b49b16e03bf5b3a8e0410469

28. Kim H-S, Wang J-H, Lim I-H, Park K-T, Yeon S-C, Lee H-C. Three-dimensional volume assessment accuracy in computed tomography using a phantom. J Vet Clin [Internet]. 2013;30(4):268–72. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84885214839&partnerID=40&md5=8bdb91ba80958dd87552de66d35071a1
29. Luntz M, Malatskey S, Tan M, Bar-Meir E, Ruimi D. Volume of mastoid pneumatization: three-dimensional reconstruction with ultrahigh-resolution computed tomography. Ann Otol Rhinol Laryngol. 2001 May;110(5 Pt 1):486–90.
30. Da Silveira PF, Fontana MP, Oliveira HW, Vizzotto MB, Montagner F, Silveira HLE, et al. CBCT-based volume of simulated root resorption - influence of FOV and voxel size. Int Endod J [Internet]. 2015;48(10):959–65. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L615183361
31. Pinchi V, Pradella F, Buti J, Baldinotti C, Focardi M, Norelli G-A. A new age estimation procedure based on the 3D CBCT study of the pulp cavity and hard tissues of the teeth for forensic purposes: A pilot study. J Forensic Leg Med. 2015 Nov;36:150–7.
32. Kamburoglu K, Kursun S, Kilic C, Ozen T. Accuracy of virtual models in the assessment of maxillary defects. Imaging Sci Dent. 2015 Mar;45(1):23–9.
33. Kobayashi Y, Satoh K, Kanamori D, Mizutani H, Fujii N, Aizawa T, et al. Evaluating the exposure dose of 320-row area detector computed tomography and its reliability in the measurement of bone defect in alveolar cleft. J Oral Maxillofac Surgery, Med Pathol [Internet]. 2017 Jul;29(4):350–7. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85017377882&doi=10.1016%2Fj.ajoms.2017.03.006&partnerID=40&md5=1b4b105a2a0553755f46198d1b8ad516
34. Sonmez G, Koc C, Kamburoglu K. Accuracy of linear and volumetric measurements of artificial ERR cavities by using CBCT images obtained at 4 different voxel sizes and measured by using 4 different software: an ex vivo research. Dentomaxillofac Radiol. 2018 Dec;47(8):20170325.
35. Pinsky HM, Dyda S, Pinsky RW, Misch KA, Sarment DP, H.M. P, et al. Accuracy of three-dimensional measurements using cone-beam CT. Dentomaxillofacial Radiol [Internet]. 2006;35(6):410–6. Available from:

http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L44904797

36. Agbaje JO, Jacobs R, Maes F, Michiels K, van Steenberghe D, J.O. A, et al. Volumetric analysis of extraction sockets using cone beam computed tomography: a pilot study on ex vivo jaw bone. J Clin Periodontol [Internet]. 2007;34(11):985–90. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L47574499
37. Coronado C, Arriagada O, Suazo Galdames I. Easy and unbiased determination of the maxillary sinus volume TT - Fácil determinación y sin sesgo del volumen del seno maxilar. Int j morphol [Internet]. 2011;29(4):1375–8. Available from: http://www.scielo.cl/scielo.php?script=sci_arttext&pid=S0717-95022011000400051
38. Ahlowalia MS, Patel S, Anwar HMS, Cama G, Austin RS, Wilson R, et al. Accuracy of CBCT for volumetric measurement of simulated periapical lesions. Int Endod J [Internet]. 2013;46(6):538–46. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23216253
39. Amirlak B, Tang CJ, Becker D, Palomo JM, Gosain AK, B. A, et al. Volumetric analysis of simulated alveolar cleft defects and bone grafts using cone beam computed tomography. Plast Reconstr Surg [Internet]. 2013;131(4):854–9. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L368976022
40. Esposito, S.A., Huybrechts, B., Slagmolen, P., Cotti, E., Coucke, W., Pauwels, R., Lambrechts, P., and Jacobs R. A novel method to estimate the volume of bone defects using cone-beam computed tomography: an in vitro study. J Endod [Internet]. 2013;39(9):1111–5. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23953281
41. Liang Y-H, Jiang L, Gao X-J, Shemesh H, Wesselink PR, Wu M-K, et al. Detection and measurement of artificial periapical lesions by cone-beam computed tomography. Int Endod J [Internet]. 2014;47(4):332–8. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L608094882
42. Saccucci M, Cipriani F, Carderi S, Di Carlo G, D'Attilio M, Rodolfino D, et al.

Gender assessment through three-dimensional analysis of maxillary sinuses by means of cone beam computed tomography. Eur Rev Med Pharmacol Sci [Internet]. 2015;19(2):185–93. Available from: http://www.ncbi.nlm.nih.gov/pubmed/25683929

43. Linning E and DM. Volumetric Measurement Pulmonary Ground-Glass Opacity Nodules with Multi-detector CT. Effect of Various Tube Current on Measurement Accuracy-A Chest CT Phantom Study. Acad Radiol [Internet]. 2009;16(8):934–9. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L50503727

44. Marten K, Funke M, Engelke C. Flat panel detector-based volumetric CT: Prototype evaluation with volumetry of small artificial nodules in a pulmonary phantom. J Thorac Imaging [Internet]. 2004;19(3):156–63. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-3342880848&doi=10.1097%2F01.rti.0000131591.12777.a8&partnerID=40&md5=5bdb5330dfe5054036437d2c8bd287b1

45. Goo JM, Tongdee T, Tongdee R, Yeo K, Hildebolt CF, Bae KT. Volumetric measurement of synthetic lung nodules with multi-detector row CT: Effect of various image reconstruction parameters and segmentation thresholds on measurement accuracy. Radiology [Internet]. 2005;235(3):850–6. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-18844382442&doi=10.1148%2Fradiol.2353040737&partnerID=40&md5=46f069a5ccd415eeda89b71b331a9984

46. Kuhnigk J-M, Dicken V, Bornemann L, Bakai A, Wormanns D, Krass S, et al. Morphological segmentation and partial volume analysis for volumetry of solid pulmonary lesions in thoracic CT scans. IEEE Trans Med Imaging [Internet]. 2006;25(4):417–34. Available from: http://www.ncbi.nlm.nih.gov/pubmed/16608058

47. Bolte H, Riedel C, Knöss N, Freitag S, Hoffmann B, Heller M, et al. Computed tomography-based lung nodule volumetry - Do optimized reconstructions of routine protocols achieve similar accuracy, reproducibility and interobserver variability to that of special volumetry protocols? RoFo Fortschritte auf dem Gebiet der Rontgenstrahlen und der Bildgeb Verfahren [Internet]. 2007;179(3):276–81. Available from:

http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L46769329

48. Bolte H, Riedel C, Riede C, Müller-Hülsbeck S, Freitag-Wolf S, Kohl G, et al. Precision of computer-aided volumetry of artificial small solid pulmonary nodules in ex vivo porcine lungs. Br J Radiol [Internet]. 2007;80(954):414–21. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L47322228
49. Larici AR, Storto ML, Torge M, Mereu M, Molinari F, Maggi F, et al. Automated volumetry of pulmonary nodules on multidetector CT: Influence of slice thickness, reconstruction algorithm and tube current. Preliminary results. Radiol Medica [Internet]. 2008;113(1):29–42. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-40749155455&doi=10.1007%2Fs11547-008-0231-3&partnerID=40&md5=a95cc9862f5afcfa03c0191eed8acfd9
50. Way TW, Chan HP, Goodsitt MM, Sahiner B, Hadjiiski LM, Zhou C CA. Effect of CT scanning parameters on volumetric measurements of pulmonary nodules by 3D active contour segmentation: A phantom study. Phys Med Biol [Internet]. 2008;53(5):1295–312. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L351594427
51. Marten K, Dullin C, Machann W, Schmid JS, DAS M, Hermann KP EC. Comparison of flat-panel-detector-based CT and multidetector-row CT in automated volumetry of pulmonary nodules using an anthropomorphic chest phantom. Br J Radiol [Internet]. 2009;82(981):716–23. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L355267632
52. Cavalcanti MG, Vannier MW. Measurement of the volume of oral tumors by three-dimensional spiral computed tomography. Dentomaxillofac Radiol [Internet]. 2000;29(1):35–40. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L33427126
53. Dudeck O, Jurczyk K, Abdo G, Pech M, Wieners G, Rüfenacht DA, et al. Volume determination of intracranial aneurysms using 16-row multislice computed

tomography angiography: A systematic in vitro analysis of different reconstruction methods. J Comput Assist Tomogr [Internet]. 2005;29(6):851–7. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L41689554

54. Walde TA, Weiland DE, Leung SB, Kitamura N, Sychterz CJ, Engh Jr. CA, et al. Comparison of CT, MRI, and radiographs in assessing pelvic osteolysis: A cadaveric study. Clin Orthop Relat Res [Internet]. 2005;(437):138–44. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-23244454941&doi=10.1097%2F01.blo.0000164028.14504.46&partnerID=40&md5=acc26a971377077efd6873ea83a5c02e
55. Sommer G, Bouley D, Frisoli J, Pierce L, Sandner-Porkristl D, Fahrig R. Determination of 3-dimensional zonal renal volumes using contrast-enhanced computed tomography. J Comput Assist Tomogr [Internet]. 2007;31(2):209–13. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L46573357
56. Keil S, Plumhans C, Behrendt FF, Stanzel S, Suehling M, Mühlenbruch G, et al. Semi-automated quantification of hepatic lesions in a phantom. Invest Radiol [Internet]. 2009;44(2):82–8. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L354975082
57. M. Fabel, J. Biederer, A. Jochens, L. Bornemann, G. Soza, M. Heller HB. Semi-automated volumetric analysis of artificial lymph nodes in a phantom study. Eur J Radiol [Internet]. 2011;80(3):e451–7. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L51157907
58. Osaki TH, de Castro DK, Yabumoto C, Mingkwansook V, Ting E, Nallasamy N, et al. Comparison of methodologies in volumetric orbitometry. Ophthal Plast Reconstr Surg [Internet]. 2013;29(6):431–6. Available from: http://www.ncbi.nlm.nih.gov/pubmed/24217474
59. Lubner MG, Dustin Pooler B, del Rio AM, Durkee B, Pickhardt PJ. Volumetric evaluation of hepatic tumors: multi-vendor, multi-reader liver phantom study. Abdom Imaging [Internet]. 2014;39(3):488–96. Available from:

http://www.ncbi.nlm.nih.gov/pubmed/24492936

60. Haverkamp K, Harder LK, Kuhnt NSM, Lupke M, Nolte I, Wefstaedt P. Validation of canine prostate volumetric measurements in computed tomography determined by the slice addition technique using the Amira program. BMC Vet Res. 2019 Feb;15(1):49.
61. Liu Y, Olszewski R, Alexandroni ES, Enciso R, Xu T, Mah JK, et al. The validity of in vivo tooth volume determinations from cone-beam computed tomography. Angle Orthod [Internet]. 2010;80(1):160–6. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L355618748
62. Bayram M, Kayipmaz S, Sezgin OS, Küçük M. Volumetric analysis of the mandibular condyle using cone beam computed tomography. Eur J Radiol [Internet]. 2012;81(8):1812–6. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21680124
63. Cotter MM, Whyms BJ, Kelly MP, Doherty BM, Gentry LR, Bersu ET, et al. Hyoid Bone Development: An Assessment Of Optimal CT Scanner Parameters and Three-Dimensional Volume Rendering Techniques. Anat Rec [Internet]. 2015;298(8):1408–15. Available from: http://www.ncbi.nlm.nih.gov/pubmed/25810349
64. Sang Y-H, Hu H-C, Lu S-H, Wu Y-W, Li W-R, Tang Z-H. Accuracy Assessment of Three-dimensional Surface Reconstructions of In vivo Teeth from Cone-beam Computed Tomography. Chin Med J (Engl). 2016 Jun;129(12):1464–70.
65. Garcia-Sanz V, Bellot-Arcis C, Hernandez V, Serrano-Sanchez P, Guarinos J, Paredes-Gallardo V. Accuracy and Reliability of Cone-Beam Computed Tomography for Linear and Volumetric Mandibular Condyle Measurements. A Human Cadaver Study. Sci Rep. 2017 Sep;7(1):11993.
66. de Rezende Barbosa GL, Wood JS, Pimenta LA, Maria de Almeida S, Tyndall DA. Comparison of different methods to assess alveolar cleft defects in cone beam CT images. Dentomaxillofac Radiol [Internet]. 2016;45(2):20150332. Available from: http://www.ncbi.nlm.nih.gov/pubmed/26648387
67. Elashiry M, Meghil MM, Kalathingal S, Buchanan A, Elrefai R, Looney S, et al. Application of radiopaque micro-particle fillers for 3-D imaging of periodontal pocket analogues using cone beam CT. Dent Mater. 2018 Apr;34(4):619–28.
68. Dudeck O, Okuducu AF, Jordan O, Tesmer K, Pech M, Weigang E, et al. Volume

changes of experimental carotid sidewall aneurysms due to embolization with liquid embolic agents: A multidetector CT angiography study. Cardiovasc Intervent Radiol [Internet]. 2006;29(6):1053–9. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L44661957

69. Albuquerque MAP, Gaia BF, Cavalcanti MGP. Oral cleft volumetric assessment by 3D multislice computed tomographic images. Int J Oral Maxillofac Surg [Internet]. 2011;40(11):1280–8. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-82955203381&doi=10.1016%2Fj.ijom.2011.05.015&partnerID=40&md5=d63eee0d4fe77c915e77647d19c41b09
70. Kirmeier R, Arnetzl C, Robl T, Payer M, Lorenzoni M, Jakse N. Reproducibility of volumetric measurements on maxillary sinuses. Int J Oral Maxillofac Surg [Internet]. 2011;40(2):195–9. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21074367
71. Divani AA, Majidi S, Luo X, Souslian FG, Zhang J, Abosch A, et al. The ABCs of accurate volumetric measurement of cerebral hematoma. Stroke [Internet]. 2011;42(6):1569–74. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L51422834
72. Prionas ND, Ray S, Boone JM. Volume assessment accuracy in computed tomography: a phantom study. J Appl Clin Med Phys [Internet]. 2010;11(2):3037. Available from: http://www.ncbi.nlm.nih.gov/pubmed/20592693
73. Albuquerque MA, Gaia BF, Cavalcanti MGP. Comparison between multislice and cone-beam computerized tomography in the volumetric assessment of cleft palate. Oral Surg Oral Med Oral Pathol Oral Radiol Endod [Internet]. 2011;112(2):249–57. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21664153
74. Parrilli A, Falcioni S, Fini M, Affatato S. Is micro-computed tomography useful for wear assessment of ceramic femoral heads? A preliminary evaluation of volume measurements. J Appl Biomater Funct Mater [Internet]. 2016;14(4):e483–9. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L613209230

75. Grauer D, Cevidanes LSH, Styner MA, Ackerman JL, Proffit WR. Pharyngeal airway volume and shape from cone-beam computed tomography: relationship to facial morphology. Am J Orthod Dentofacial Orthop. 2009 Dec;136(6):805–14.
76. Miracle AC, Mukherji SK. Conebeam CT of the head and neck, part 1: physical principles. AJNR Am J Neuroradiol. 2009 Jun;30(6):1088–95.
77. Kasaven CP, Ivekovic S, McIntyre GT, Gillgrass T, Thomson DA, Menhinick A, et al. Validation of the volumetric measurement of a simulated maxillary alveolar bone defect using cone-beam computed tomography. Cleft Palate-Craniofacial J [Internet]. 2013;50(6):e115–20. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84888596061&doi=10.1597%2F12-161&partnerID=40&md5=380b6e0ff9616981e07af90e239a7367
78. Wang Y, He S, Yu L, Li J, Chen S. Accuracy of volumetric measurement of teeth in vivo based on cone beam computer tomography. Orthod Craniofacial Res [Internet]. 2011;14(4):206–12. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-80054835358&doi=10.1111%2Fj.1601-6343.2011.01525.x&partnerID=40&md5=75c47096196836b9cbcd98563db2036e
79. Umanjec-Korac S, Parsa A, Darvishan Nikoozad A, Wismeijer D, Hassan B. Accuracy of cone beam computed tomography in following simulated autogenous graft resorption in maxillary sinus augmentation procedure: an ex vivo study. Dentomaxillofac Radiol [Internet]. 2016;45(6):20160092. Available from: http://www.ncbi.nlm.nih.gov/pubmed/27225346
80. Whiting P, Westwood M, Burke M, Sterne J, Glanville J. Systematic reviews of test accuracy should search a range of databases to identify primary studies. J Clin Epidemiol. 2008 Apr;61(4):357–64.

Appendix A – PUBMED SEARCH

((Airway[All Fields] OR (Upper[All Fields] AND airway[All Fields]) OR ("paranasal sinuses"[MeSH Terms] OR ("paranasal"[All Fields] AND "sinuses"[All Fields]) OR "paranasal sinuses"[All Fields] OR "sinus"[All Fields]) OR Lesions[All Fields] OR (Volumes[All Fields] AND lesions[All Fields]) OR (Volume[All Fields] AND ("bone and bones"[MeSH Terms] OR ("bone"[All Fields] AND "bones"[All Fields]) OR "bone and bones"[All Fields] OR "bone"[All Fields]) AND ("dental caries"[MeSH Terms] OR ("dental"[All Fields] AND "caries"[All Fields]) OR "dental caries"[All Fields] OR "cavities"[All Fields])) OR (("bone and bones"[MeSH Terms] OR ("bone"[All Fields] AND "bones"[All Fields]) OR "bone and bones"[All Fields] OR "bone"[All Fields]) AND ("abnormalities"[Subheading] OR "abnormalities"[All Fields] OR "defects"[All Fields])) OR (("bone and bones"[MeSH Terms] OR ("bone"[All Fields] AND "bones"[All Fields]) OR "bone and bones"[All Fields] OR "bone"[All Fields]) AND volume[All Fields]) OR (("tooth"[MeSH Terms] OR "tooth"[All Fields]) AND volume[All Fields]) OR (Volumetric[All Fields] AND ("Measurement (Lond)"[Journal] OR "Measurement (Mahwah N J)"[Journal] OR "measurement"[All Fields]) AND intraosseous[All Fields] AND lesions[All Fields]) OR (volume[All Fields] AND stability[All Fields]) OR Cleft[All Fields] OR (Cleft[All Fields] AND ("abnormalities"[Subheading] OR "abnormalities"[All Fields] OR "defects"[All Fields])) OR (("dental pulp cavity"[MeSH Terms] OR ("dental"[All Fields] AND "pulp"[All Fields] AND "cavity"[All Fields]) OR "dental pulp cavity"[All Fields] OR ("pulp"[All Fields] AND "chamber"[All Fields]) OR "pulp chamber"[All Fields]) AND volume[All Fields]) OR (Condylar[All Fields] AND volume[All Fields]) OR (Periapical[All Fields] AND lesion[All Fields])) AND ((((((((((("tomography, x-ray computed"[MeSH Terms] OR ("tomography, x-ray computed"[MeSH Terms] OR ("tomography"[All Fields] AND "x-ray"[All Fields] AND "computed"[All Fields]) OR "x-ray computed tomography"[All Fields] OR "tomography, x ray computed"[All Fields])) OR "multidetector computed tomography"[MeSH Terms]) OR ("multidetector computed tomography"[MeSH Terms] OR ("multidetector"[All Fields] AND "computed"[All Fields] AND "tomography"[All Fields]) OR "multidetector computed tomography"[All Fields])) OR "tomography, spiral computed"[MeSH Terms]) OR ("tomography, spiral computed"[MeSH Terms] OR ("tomography"[All Fields] AND "spiral"[All Fields] AND "computed"[All Fields]) OR "spiral computed tomography"[All Fields] OR ("tomography"[All Fields] AND "spiral"[All Fields] AND "computed"[All Fields]) OR "tomography, spiral computed"[All Fields])) OR "cone-beam computed

tomography"[MeSH Terms]) OR ("cone-beam computed tomography"[MeSH Terms] OR ("cone-beam"[All Fields] AND "computed"[All Fields] AND "tomography"[All Fields]) OR "cone-beam computed tomography"[All Fields] OR ("cone"[All Fields] AND "beam"[All Fields] AND "computed"[All Fields] AND "tomography"[All Fields]) OR "cone beam computed tomography"[All Fields])) OR "tomography scanners, x-ray computed"[MeSH Terms]) OR ("tomography scanners, x-ray computed"[MeSH Terms] OR ("tomography"[All Fields] AND "scanners"[All Fields] AND "x-ray"[All Fields] AND "computed"[All Fields]) OR "x-ray computed tomography scanners"[All Fields] OR "tomography scanners, x ray computed"[All Fields])) OR "x-ray microtomography"[MeSH Terms]) OR ("x-ray microtomography"[MeSH Terms] OR ("x-ray"[All Fields] AND "microtomography"[All Fields]) OR "x-ray microtomography"[All Fields] OR "x ray microtomography"[All Fields]))) AND ((Volumetric[All Fields] AND measurements[All Fields]) OR (volumetric[All Fields] AND segmentation[All Fields]))

Appendix B – LILACS SEARCH

(tw:((mh:(seios paranasais)) OR (mh:(paranasal sinuses)) OR (mh:(senos paranasales)) OR (mh:(osso e ossos)) OR (mh:(bone AND bones)) OR (mh:(huesos)) OR (mh:(cárie dentária)) OR (mh:(dental caries)) OR (mh:(caries dental)) OR (mh:(dente)) OR (mh:(tooth)) OR (mh:(diente)) OR (mh:(cavidade pulpar)) OR (mh:(dental pulp cavity)) OR (mh:(cavidad pulpar)) OR (mh:(cistos ósseos)) OR (mh:(bone cysts)) OR (mh:(quistes óseos)) OR (mh:(fissura palatina)) OR (mh:(cleft palate)) OR (mh:(fisura del paladar)) OR (mh:(côndilo mandibular)) OR (mh:(mandibular condyle)) OR (mh:(cóndilo mandibular)) OR (mh:(doenças periapicais)) OR (mh:(periapical diseases)) OR (mh:(enfermedades periapicales)) OR (tw:(via aérea)) OR (tw:(vias aéreas)) OR (tw:(airway)) OR (tw:(vía aérea)) OR (tw:(vías aéreas)) OR (tw:(vias aéreas superiores)) OR (tw:(upper airway)) OR (tw:(vías aéreas superiores)) OR (tw:(seio)) OR (tw:(sinus)) OR (tw:(seno)) OR (tw:(lesões)) OR (tw:(lesão)) OR (tw:(lesions)) OR (tw:(lesion)) OR (tw:(lesión)) OR (tw:(cavidades ósseas)) OR (tw:(bone cavities)) OR (tw:(cavidades óseas)) OR (tw:(defeitos ósseos)) OR (tw:(bone defects)) OR (tw:(defectos óseos)) OR (tw:(lesão intraóssea)) OR (tw:(lesões intraósseas)) OR (tw:(intraosseous lesions)) OR (tw:(fenda palatina)) OR (tw:(cleft defects)) OR (tw:(câmara pulpar)) OR (tw:(pulp chamber)) OR (tw:(cámara pulpar)) OR (tw:(condilar)) OR (tw:(condylar)) OR (tw:(côndilo)) OR (tw:(condyle)) OR (tw:(cóndilo)) OR (tw:(lesão periapical)) OR (tw:(periapical lesion)) OR (tw:(lesión periapical)))) AND (tw:((mh:(tomografia computadorizada por raios x)) OR (mh:(tomography, x-ray computed)) OR (mh:(tomografía computarizada por rayos x)) OR (mh:(tomografia computadorizada multidetectores)) OR (mh:(multidetector computed tomography)) OR (mh:(tomografía computarizada multidetector)) OR (mh:(tomografia computadorizada espiral)) OR (mh:(tomography, spiral computed)) OR (mh:(tomografía computarizada espiral)) OR (mh:(tomografia computadorizada de feixe cônico)) OR (mh:(cone-beam computed tomography)) OR (mh:(tomografía computarizada de haz cónico)) OR (mh:(tomógrafos computadorizados)) OR (mh:(tomography scanners, x-ray computed)) OR (mh:(tomógrafos computarizados por rayos x)) OR (mh:(microtomografia por raio-x)) OR (mh:(x-ray microtomography)) OR (mh:(microtomografía por rayos x)) OR (tw:(tomography, x-ray computed)) OR (tw:(tomografia computadorizada por raios x)) OR (tw:(tomografía computarizada por rayos x)) OR (tw:(tomografia computadorizada multidetectores)) OR (tw:(multidetector

computed tomography)) OR (tw:(tomografía computarizada multidetector)) OR (tw:(tomografia computadorizada espiral)) OR (tw:(tomography, spiral computed)) OR (tw:(tomografía computarizada espiral)) OR (tw:(tomografia computadorizada de feixe cônico)) OR (tw:(cone-beam computed tomography)) OR (tw:(tomografía computarizada de haz cónico)) OR (tw:(tomógrafos computadorizados)) OR (tw:(tomography scanners, x-ray computed)) OR (tw:(tomógrafos computarizados por rayos x)) OR (tw:(microtomografia por raio-x)) OR (tw:(x-ray microtomography)) OR (tw:(microtomografía por rayos x)))) AND (tw:((tw:(medidas volumétricas)) OR (tw:(volumetric measurements)) OR (tw:(medida volumétrica)) OR (tw:(volumetric measurement)) OR (tw:(medidas)) OR (tw:(medida)) OR (tw:(measurements)) OR (tw:(measurement)) OR (tw:(volumétrica)) OR (tw:(volumétricas)) OR (tw:(volumetric)) OR (tw:(volumétrico)) OR (tw:(volume)) OR (tw:(volumen)) OR (tw:(segmentação volumétrica)) OR (tw:(volumetric segmentation)) OR (tw:(segmentación volumétrica)) OR (tw:(segmentación)) OR (tw:(segmentação)) OR (tw:(segmentation)) OR (tw:(análise volumétrica)) OR (tw:(análise)) OR (tw:(análise de volume)) OR (tw:(volumetric analysis)) OR (tw:(analysis)) OR (tw:(análisis volumétrico)) OR (tw:(análisis)) OR (tw:(análisis de volumen)))) AND (instance:"regional") AND (db:("LILACS"))

Appendix C – EMBASE SEARCH

('paranasal sinus'/exp OR 'nasal sinus' OR 'paranasal cavity' OR 'paranasal sinus' OR 'paranasal sinuses' OR 'sinus paranasalis' OR 'bone'/exp OR 'bone' OR 'bone and bones' OR 'dental caries'/exp OR 'caries' OR 'caries, dental' OR 'dental caries' OR 'dental decay' OR 'root caries' OR 'tooth caries' OR 'tooth decay' OR 'dental pulp cavity'/exp OR 'dental pulp cavity' OR 'pulp cavity (tooth)' OR 'tooth pulp cavity' OR 'bone cyst'/exp OR 'bone cyst' OR 'bone cysts' OR 'cyst, bone' OR 'nasopharynx airway'/exp OR 'nasopharyngeal airway' OR 'nasopharynx airway' OR 'rhinopharynx airway' OR 'oropharynx airway'/exp OR 'oral airway' OR 'oropharyngeal airway' OR 'oropharynx airway' OR 'upper respiratory tract'/exp OR 'respiratory tract, upper' OR 'upper air tract' OR 'upper respiration tract' OR 'upper respiratory tract' OR 'bone lesion'/exp OR 'bone lesion' OR 'skeletal lesion' OR volume OR 'bone defect'/exp OR 'bone defect' OR 'measurement'/exp OR 'measurement' OR 'cleft palate'/exp OR 'cleft maxilla palate' OR 'cleft palate' OR 'cleft palatum' OR 'palatal cleft' OR 'palate, cleft' OR 'palatum fissum' OR 'prepalatal cleft palate' OR 'mandible condyle'/exp OR 'condylar process, lower jaw' OR 'condylar process, mandible' OR 'condylar process, mandibular' OR 'lower jaw condylar process' OR 'mandible condylar process' OR 'mandible condyle' OR 'mandibula condylar process' OR 'mandibular condylar process' OR 'mandibular condyle' OR 'processus condylaris mandibulae' OR 'tooth periapical disease'/exp OR 'dental granuloma' OR 'periapical disease' OR 'periapical diseases' OR 'periapical granuloma' OR 'periapical lesion' OR 'periapical periodontitis' OR 'tooth granuloma' OR 'tooth periapical disease' OR 'tooth periapical granuloma' OR 'airway'/exp OR 'airway' OR 'upper airway' OR 'lesions and defects'/exp OR 'lesions and defects') AND ('x-ray computed tomography'/exp OR 'ct scan' OR 'ct scanning' OR 'tomography, x-ray computed' OR 'x-ray computed tomography' OR 'multidetector computed tomography'/exp OR 'mdct' OR 'msct' OR 'multi detector ct' OR 'multi detector computed tomography' OR 'multi detector computer assisted tomography' OR 'multi detector helical ct' OR 'multi detector helical computed tomography' OR 'multi detector row ct' OR 'multi detector row computed tomography' OR 'multi detector row computer assisted tomography' OR 'multi detector row computer tomography' OR 'multi detector spiral ct' OR 'multi detector spiral computed tomography' OR 'multi slice ct' OR 'multi slice computed tomography' OR 'multi slice computerized tomography' OR 'multi slice helical ct' OR 'multi slice helical computed tomography' OR 'multi slice spiral ct' OR 'multi slice spiral computed tomography' OR 'multidetector ct' OR

'multidetector computed tomography' OR 'multidetector computer assisted tomography' OR 'multidetector helical ct' OR 'multidetector helical computed tomography' OR 'multidetector row ct' OR 'multidetector row computed tomography' OR 'multidetector row computer assisted tomography' OR 'multidetector row computer tomography' OR 'multidetector spiral ct' OR 'multidetector spiral computed tomography' OR 'multislice ct' OR 'multislice computed tomography' OR 'multislice computerized tomography' OR 'multislice helical ct' OR 'multislice helical computed tomography' OR 'multislice spiral ct' OR 'multislice spiral computed tomography' OR 'spiral computer assisted tomography'/exp OR 'computer assisted tomography, spiral' OR 'helical ct' OR 'helical computed tomography' OR 'helical computer assisted tomography' OR 'helical computer tomography' OR 'spiral ct' OR 'spiral computed tomography' OR 'spiral computer assisted tomography' OR 'spiral computer tomography' OR 'tomography, spiral computed' OR 'cone beam computed tomography'/exp OR 'cbct (cone beam computed tomography)' OR 'cone beam ct' OR 'cone beam computed tomography' OR 'cone beam computerized tomography' OR 'cone-beam computed tomography' OR 'spiral cone-beam computed tomography' OR 'volume ct' OR 'volume computed tomography' OR 'volumetric ct' OR 'volumetric computed tomography' OR 'computed tomography scanner'/exp OR 'acqsim' OR 'accell proceed' OR 'aquilion 16' OR 'aquilion 32' OR 'aquilion one' OR 'aquilionone' OR 'asteion s4' OR 'bicor plus' OR 'bright speed' OR 'brightspeed' OR 'briliiance 64' OR 'brilliance 40' OR 'brilliance 6' OR 'brilliance 64' OR 'brilliance ict' OR 'c-150 xl ultrafast' OR 'ct scanner' OR 'definition flash' OR 'discovery (computed tomography scanner)' OR 'discovery ct750 hd' OR 'eclos (device)' OR 'hispeed advantage ct/i' OR 'hi-speed advantage' OR 'hi-speed advantage ct/i' OR 'hispeed qx/i' OR 'high speed advantage scanner' OR 'highspeed (computed tomography scanner)' OR 'imatron c-150' OR 'ingenuity (device)' OR 'light speed (device)' OR 'lightspeedplus' OR 'lightspeed vct' OR 'mx 8000' OR 'mx8000' OR 'multispeed ultra 16x' OR 'mx8000 idt 16 ct' OR 'mx8000 idt 16 ct scanner' OR 'mx8000 idt ct scanner' OR 'optima ct 660' OR 'prospeed' OR 'smx-100ct-sv' OR 'somatom volume zoom' OR 'sensation 10' OR 'sensation 64' OR 'siemens definition 64' OR 'siemens sensation 16' OR 'somato volume zoom 4' OR 'somatom definition' OR 'somatom emotion' OR 'somatom sensation 16' OR 'somatom spirit' OR 'tomoscan' OR 'toshiba aquilion 64' OR 'twin flash (computed tomography scanner)' OR 'vct 64' OR 'x-vigor' OR 'x-tek benchtop ct160xi' OR 'xtremect' OR 'xvision' OR 'cat scanner, x ray' OR 'cat scanner, x-ray' OR 'cat scanners, x ray' OR 'cat scanners, x-ray' OR

'computed tomography scanner' OR 'computed tomography scanner, x ray' OR 'computed tomography scanner, x-ray' OR 'computed tomography scanners, x ray' OR 'computed tomography scanners, x-ray' OR 'computed tomography scanning systems' OR 'computer tomography scanner' OR 'emi scanner' OR 'ict 256' OR 'ict256' OR 'scanner, computed tomography' OR 'scanner, x-ray cat' OR 'scanners, x-ray cat' OR 'system, x-ray, tomography, computed' OR 'tomography scanners, x ray computed' OR 'tomography scanners, x-ray computed' OR 'tomography, x-ray computed, scanner' OR 'tomography, x-ray computed, scanners' OR 'x ray computed tomography scanner' OR 'x ray computed tomography scanners' OR 'x-ray cat scanner' OR 'x-ray cat scanners' OR 'x-ray computed tomography scanner' OR 'x-ray computed tomography scanners' OR 'xcat' OR 'microtomography'/exp OR 'microtomography') AND ('volumetric measurements' OR 'volumetric segmentation' OR 'volumetric analysis')

4 ARTIGO 2

Validation of volume measurements in computerized tomography images: an *in vitro* study

Formatado para ***Dentomaxillofacial Radiology***

Validation of volume measurements in computerized tomography images: an *in vitro* study

Objective: To compare volume measurements obtained in two image software, evaluating DICOM images acquired from a MDCT device and five CBCT devices, with different protocols, to the physical volume measurement.
Methods: Four pieces of a bovine leg were prepared. Marrow was removed in three pieces, leaving cortical bone exposed. One of the samples was filled with water, the other was filled with propylene glycol and the third one was left unfilled. The fourth sample had marrow totally preserved. Volume measurements were obtained by importing DICOM images into Dolphin Imaging 11.95 (Dolphin Imaging and Management Solutions, Chatsworth, CA, USA) and ITK-SNAP version 3.6.0. (http://itksnap.org). Data were analyzed with a three way ANOVA using generalized linear model (GLM) to determine the effects of voxel, software and content on mean volume percentage difference concerning tomographic protocols, adopting a significant level of 0.05.
Results: Intra and interobserver reliability were respectively 0.915 and 0.764 in Dolphin software and 0.894 and 0.766 in ITK-SNAP software. Three sources of statistically significant variation were identified: the interaction between software and content $F(3; 61) = 18.62$, $p = 0.000$, the main effect of content $F(3; 61) = 3.86$, $p = 0.014$ and the main effect of software $F(1; 61) = 52.07$, $p = 0.000$. Voxel did not show a statistically significant influence in volume measurement. Conclusion: Content and software influence in volume measurements accuracy, especially when content has grey values close to that of the adjacent tissue. Unfilled specimens showed the most accurate volume values when compared to gold standard.

Keywords: Dimensional Measurement Accuracy. Multidetector Computed Tomography. Cone-Beam Computed Tomography. *In Vitro* Techniques. Software.

INTRODUCTION

Computerized tomography images are increasingly present and opening new diagnostic possibilities.[1–3] Despite its proven effectiveness, multidetector computed tomography (MDCT) is not widely used in dental practice due to its high cost, limited availability to large medical radiological centers and the high levels of radiation exposure.[4]

Attempting to overcome the inconveniences of MDCT and the increasingly demand for better images of dentomaxillofacial complex has led to the development of cone beam computed tomography (CBCT).[5,6] CBCT is a three-dimensional technique with low radiation dose, allowing visualization of bone structures in the head and neck.[7] In a subjective comparison of image quality, images taken with a CBCT device showed significantly superior to the multi-detector CT ones. Additionally, skin dose was extremely low. These information is an indicative of the efficacy of CBCT exams in diagnosis and examination of hard tissues in the maxillofacial region.[8]

An important advantage of computed tomography images, either obtained in MDCT or CBCT equipments, usually used in digital imaging and communications in medicine (DICOM) format, is the possibility of interaction with stored data. Using specific software, this digital volume can be transformed into multiplanar images: axial, coronal and sagittal. In addition, there are some available tools that allow for measurements and create three-dimensional digital imaging.[9]

The possibility of assessing volume through computed tomography images has become increasingly common. Airway has been evaluated for volume measurements comparing pre and post-operative clinical situations,[10] associating its variation to the presence of anatomical alterations[11,12] and to the presence of cleft palate.[13,14] Regarding pathology measurements, assessment of periapical lesions volume and follow-up post-treatment bone healing could be mentioned.[15,16] Evaluation of cleft palate and predicting bone graft volume for its correction also have been obtained with CBCT images.[17,18] The greatest limitation of clinical studies[19,20] would be the absence of a gold standard. Some tests have been performed, in order to validate volume measurements, in CBCT *in vitro* studies simulating bone defects.[21,22]

Only two studies comparing different density materials volumes, using physical gold standard, were found. One compared volume obtained in multislice CT images of simulated oral clefts, with and without wax, dipped in water.[23] The other study, also

evaluating simulated oral clefts, compared pre and post grafting volume measurements in CBCT images.[24] Both showed no statistically significant differences among volume measurements.

Under clinical conditions, structures or lesions are filled or coated with soft tissue, which may interfere in acquisition or in measurement in tomographic images. Thus, it is justified to conduct a study to verify the accuracy of volume measurements in computed tomography images simulating diverse clinical and pathological situations. Therefore, the aim of this *in vitro* study was to compare volume measurements obtained in two image software, with available volume tools, evaluating DICOM images acquired in a MDCT device and in five CBCT devices, with different protocols and contents, to the physical volume measurement. Measurements reliability was also accessed.

METHODS

This *in vitro* experimental obtained the Research Committee approval in 08/17/2015. It was conducted in Oral Radiology Section, Dental School at Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, RS, Brazil.

Sample preparation

Four pieces of part of bovine leg consisting of bone, muscle and marrow (*osso buco*) were obtained in slices of about 20 mm thickness. Marrow was removed in three pieces, leaving internal cortical bone exposed. In order to simulate different clinical/pathological situations, one of the samples was filled with water, the other was filled with propylene glycol (simulating blood-like density 1.04 g/cm^3) and the third one was left unfilled. The fourth sample had marrow totally preserved. Each sample was put into an acrylic recipient in order to facilitate filling with water and propylene glycol. The bovine muscle itself was used as a soft tissue simulator to attenuate the X ray beam (Figure 1).

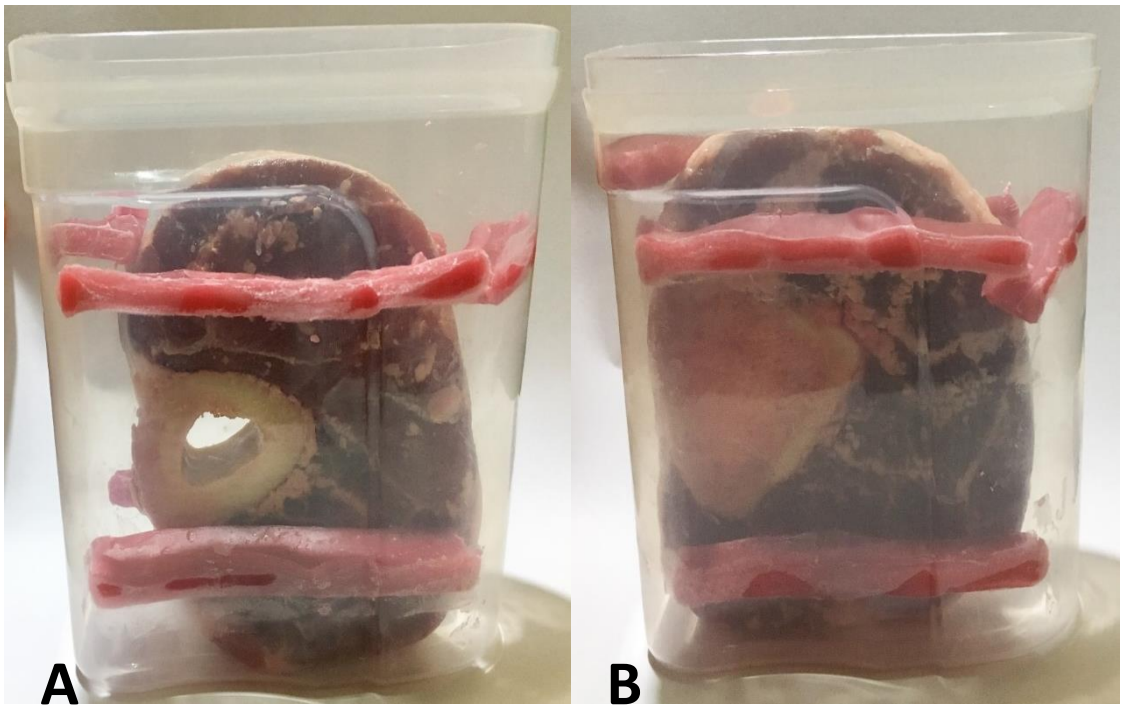

Figure 1. A: specimen without marrow. B: specimen with marrow preserved.

Image acquisition

Tomographic images were acquired in one multidetector CT device using skull protocol and reconstructed in bone and in soft tissue kernel. Images were also acquired in five CBCT devices with the routinely used protocols in clinical situations (Table 1). Specimens were placed so that x-ray beam could pass perpendicularly through muscle, bone and marrow region (Figure 2). Images were exported in DICOM format files.

Table 1. Multidetector computed tomography (MDCT) AND Cone beam computed tomography (CBCT) protocols.

EQUIPMENT	kVp***	mA****	Voxel (mm)
i-CAT Next Generation*	120	5	0.2 0.3
Orthopantomograph® OP300*	90	6.3 12.5 5.0	0.2 0.3 0.33
Pax-i3D*	85	5.2	0.12 0.2 0.3
Kodak 9000 3D*	74	10	0.2
Kodak 9500*	85	12	0.2 0.3
GE BrightSpeed 16C**	120	mA varies during aquisition (dose modulation) 8 to 200 mA (varies according to sample density)	0.625

*Cone beam computed tomography (CBCT). **Multidetector computed tomography (MDCT). ***Kilovoltage. ****Milliampere

Figure 2. A: GE BrightSpeed 16C. B: i-CAT Next Generation. C: Kodak 9500. D: Kodak 9000 3D. E: Orthopantomograph® OP300. F: Pax-i3D

Volume measurement

Gold standard

Physical volume was obtained by Archimedes' Principle. An impression of each of the four marrow region was taken using polyvinylsiloxane, addition-type, surface-activated silicone elastomer (President The Original, putty soft, Coltene) manipulated according to manufacturer's instructions (Figure 3). Excess of impression material was removed. A transparent graduated cylindrical measuring glass flask in which the 10 ml mark corresponded to 8 mm height was used. The cylinder was filled with water and

the initial level was marked. Each impression, separately, was completely immersed in the cylinder. Following the water displacement technique, the new water level was again marked. The difference between the heights represented the water displaced by the impression. The distance, in milimeters, between the two marks was obtained with a digital caliper. This value was applied in the formula:

$$\text{Volume (ml)} = \frac{\text{distance of water displaced (mm) x 10 ml}}{8 \text{ mm}}$$

and impression volume was calculated. This process was repeated three times for each impression, the average was considered the physical volume and used as the gold standard.

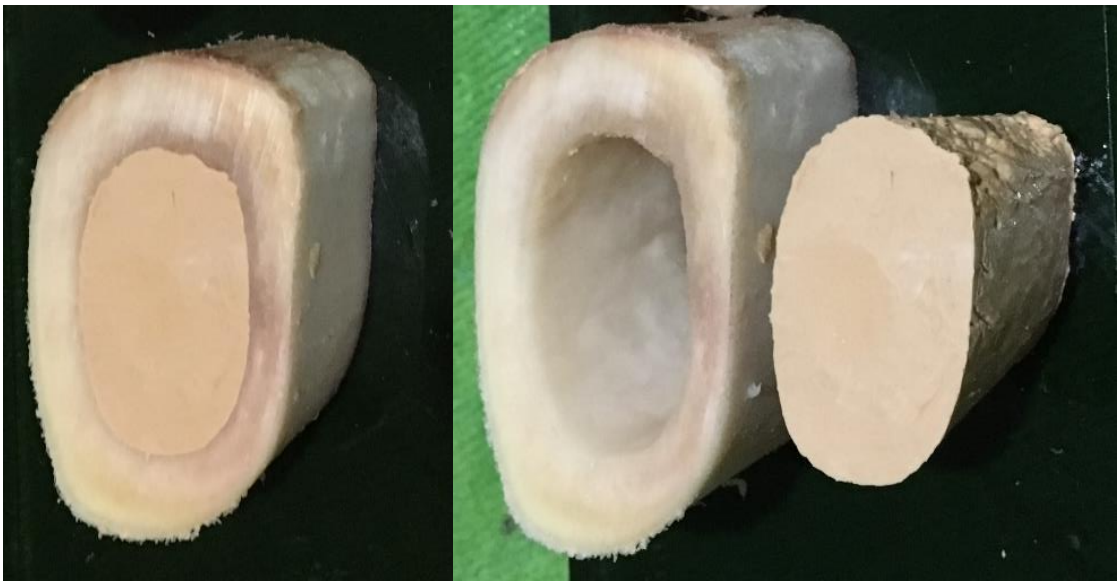

Figure 3. Impression of marrow region

Software

Volume measurements were obtained by importing all DICOM images into two image software: Dolphin Imaging 11.95 (Dolphin Imaging and Management Solutions, Chatsworth, CA, USA) and ITK-SNAP[25] version 3.6.0. (http://itksnap.org). Images were visualized on a 22-inch flat-screen monitor (Flatron E2250, 1920 9 1080 dpi; LG, Taubaté, SP, Brazil).

One trained and calibrated examiner (JACT) measured volume of all four sample images (filled with water, propylene glycol, marrow and unfilled) acquired in CT and CBCT devices, in all different protocols. All measurements were repeated three times observing at least a two weeks interval among them. The volume was obtained by averaging the three measurements.

In Dolphin Imaging software, sinus/airway tool was used to define and calculate the volumes. The sensitivity of the tool was carefully determined for each image, and the operator manually defined the extent of marrow region, performing adjustments in the sagittal, coronal and axial slices, as shown in Figure 4. Thereafter, volumetric measurements were automatically determined, in mm^3, by the software.

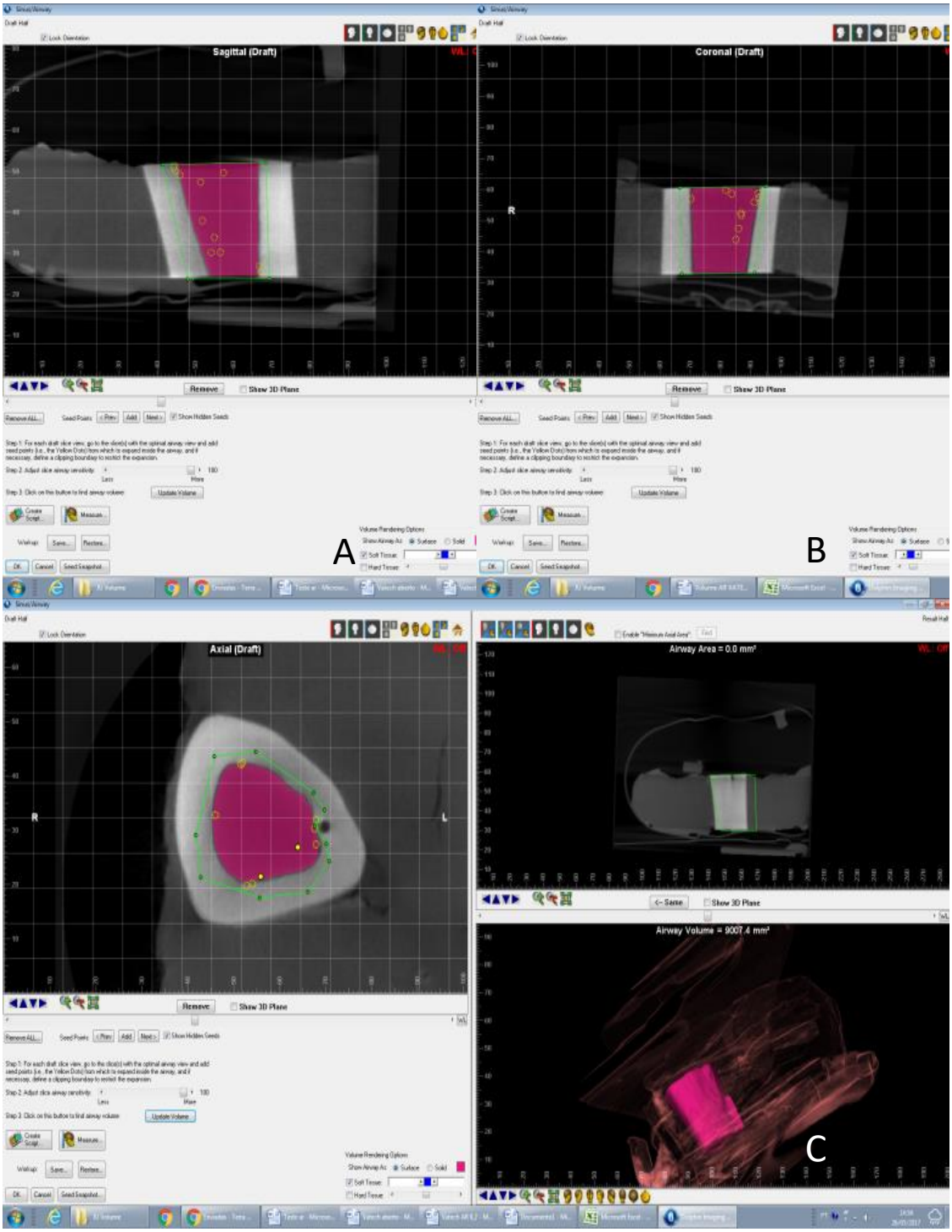

Figure 4. Dolphin Imaging software: A: sagittal view. B: coronal view. C: axial view and reconstructed 3D volume.

In ITK-SNAP, images were also semi-automatically segmented by specifying the region of interest (ROI), manually setting the parameters and initial seeds and supervising the active contour evolution[26] (Figure 5). As in Dolphin, volumetric measurements were obtained in mm^3.

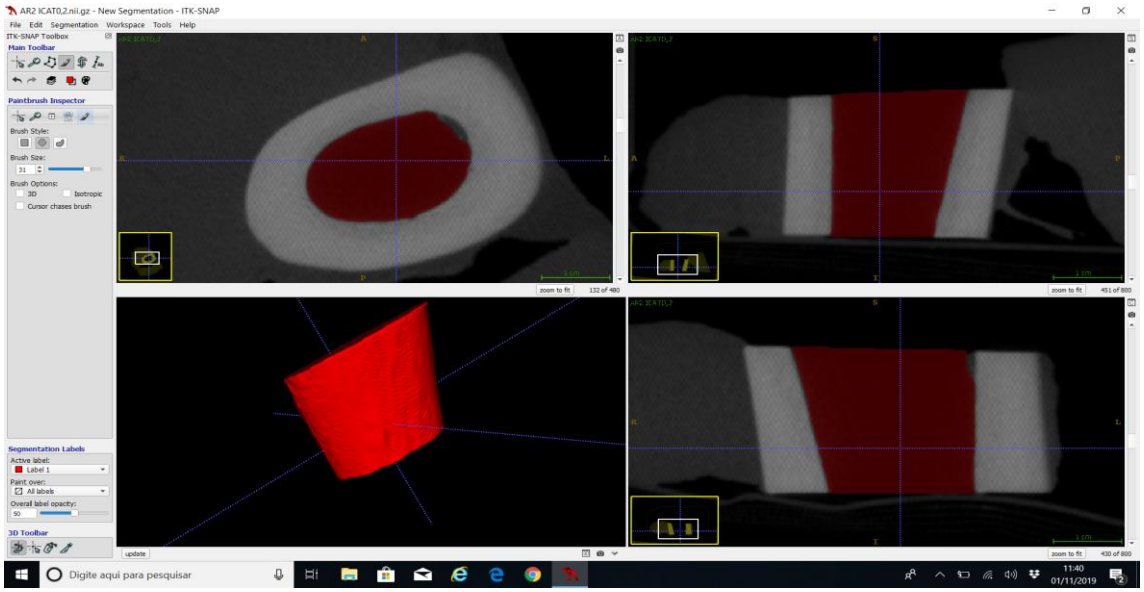

Figure 5. ITK-SNAP software: sagital, coronal and axial views and reconstructed 3D volume.

Reliability

Three examiners, one trained in Dolphin (MBV), one in ITK-SNAP (PFS) and one both in Dolphin and ITK-SNAP (JACT), conducted volume measurements using only the unfilled sample images. Measurements were repeated after a two weeks interval. Reliability was analyzed by calculating intra and interobserver errors using Intra-class Correlation Coefficient (ICC) in SPSS for Windows (SPSS Inc., Chicago, IL, EUA).

Validation of volumetric methods and statistical analysis

To validate volumetric measurements, average values obtained for each sample in both software, in all different protocols, in the five CBCT devices and in the MDCT device were registred in Microsoft Office Excel 2007 (Microsoft Corporation, Redmont, WA, EUA) and compared with gold standard. Data were analyzed using a three way ANOVA statistical test. Adopting a significant level of 0,05.”

RESULTS

Reliability

Intra and interobserver reliability, calculated using Intra-class Correlation Coefficient (ICC), were respectively 0.915 and 0.764 in Dolphin software and 0.894 and 0.766 in ITK-SNAP software.

Gold standard

Physical volumes, obtained by Archimedes' Principle, considered as gold standard and calculated using an average of three measurements, were 8326.667 mm^3 for the unfilled specimen, 6441.333 mm^3 for the water filled, 17208.33 mm^3 for the propylene glycol filled and 18620.67 mm^3 for the preserved marrow.

Validation of volumetric methods and statistical analysis

A three-way ANOVA using generalized linear model (GLM) was conducted to determine the effects of voxel, software and content on mean volume percentage difference concerning tomographic protocols. It was verified that there are three sources of statistically significant variation: the interaction between software and content $F(3; 61) = 18.62$, $p = 0.000$, the main effect of content $F(3; 61) = 3.86$, $p = 0.014$ and the main effect of software $F(1; 61) = 52.07$, $p = 0.000$. Voxel did not show a statistically significant influence in volume measurement. (Table 2)

Table 2. Three-way ANOVA using generalized linear model (GLM) to analyze the effects of voxel, software and content on mean volume percentage difference concerning tomographic protocols.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Content	3	41.61	13.871	3.86	0.014*
Voxel	4	23.83	5.958	1.66	0.172
Software	1	187.32	187.318	52.07	0.000*
Content*Voxel	12	57.47	4.789	1.33	0.225
Content*Software	3	200.97	66.990	18.62	0.000*
Voxel*Software	4	15.35	3.838	1.07	0.381
Content*Voxel*Software	12	20.21	1.684	0.47	0.926
Error	61	219.45	3.598		
Total	100	966.57			

* Asterisk represents statistical significant difference $p \leq 0.05$.

Analyzing the significant results of content and software, the boxplot (Figure 6), shows a significantly greater difference between the software for marrow compared to the other contents. In the presence of marrow content, the interaction between content and software is significant. Regardless content or software, it was observed that all measurements variated less than 10%, when compared to gold standard. Additionally, considering only unfilled, water and propylene glycol, most measurements variated less than 5%.

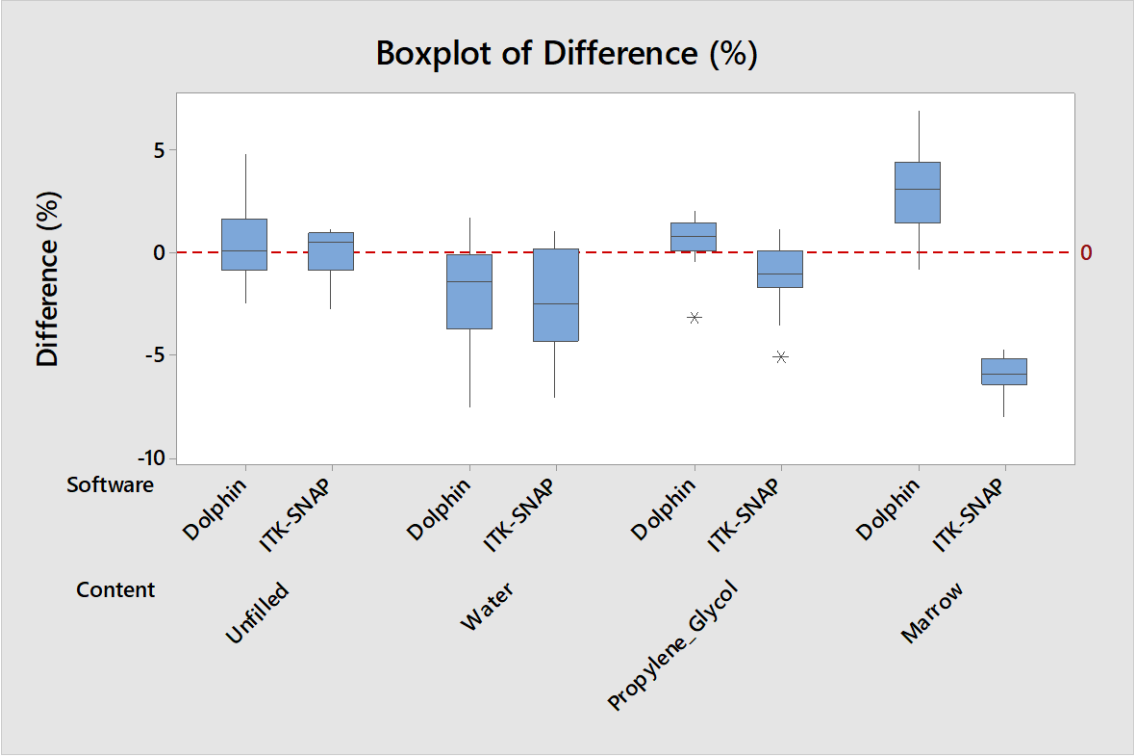

Figure 6. Difference (%) for Software and Content.

Performing the three way ANOVA without marrow content, it was found that the interaction between content and software is no longer significant. In Figure 7, marrow data were removed and the differences (%) for content and for software were individually evaluated.

Regarding content, compared to gold standard, unfilled and propylene glycol specimens showed more accurate values while water tended to underestimate. Evaluating software, Dolphin was more accurate and ITK-SNAP tended to underestimate the measurements.

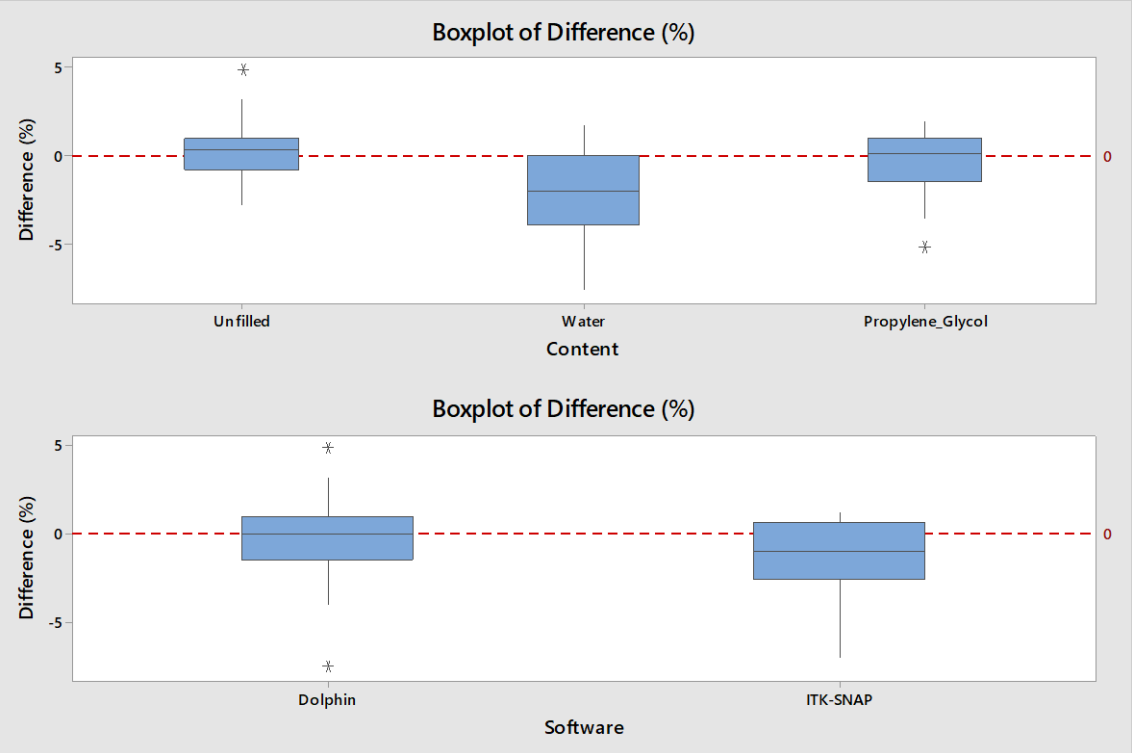

Figure 7. Difference (%) for content e for software.

DISCUSSION

In vitro researches are important to simulate different conditions under the same assessment. However, sometimes it can be very complex. In this research, the specimens were different in size and shape for each content condition, so it was difficult to observe the averages concerning under or overestimation due to a possible distortion in the values. Therefore to estimate the accuracy, the means of the differences of the analyzed content and the gold standard were compared to with each other.

Liu,[27] in a clinical study to validate volume of teeth with extraction indication for orthodontic reasons, reported that CBCT measurements seemed to be accurate. Authors did not affirm this due to the lack of requirements for accuracy of volumetric determinations. Indeed, it was observed that there is no consensus on the acceptable range for a measurement to be considered accurate and most of the studies does not explain the adopted parameters. In a study of measurements in mandible, Whyms[28] assessed accuracy comparing digital volume measurements to gold standard by calculating the average absolute relative error (ARE). In this study, an ARE 0.05, which reflects the average difference of less than 5% between anatomical and digital measurement, was considered to be acceptably accurate. However, it is still not known

how this variation could influence in clinical situations. Is 5% really a good acceptable parameter? Should this parameter be lower? Or could it be higher? Maybe it could depends on absolute structure volume. Considering this 5% variation parameter, the present study shows accurate measurements for all unfilled content measurements, regardless software, equipment or protocol.

Only a few studies compared volumes of different contents. An *in vitro* study using skulls with simulated oral cleft, submerged in a bucket of water to conduct multislice CT, compared volume measurements of the defects filled and unfilled with wax to a physical gold standard. It was observed that the sample without wax had an average volume closest to the average volume of the gold standard, compared with the sample with wax. However the three volumes were statistically equal, with reliability of 99%.[23] Amirlak in another *in vitro* oral cleft study[24], using CBCT images, compared volumes of the simulated defects with simulated bone grafts and physical gold standard and they also observed no statistically significant differences among volume measurements. However, this study observed that simulated bone graft volume measurements tends to underestimate volume. In the present study, it was also observed a tendency to underestimate marrow content, whose density is different from the cavity and closest to bone density when compared to the other three contents, making the voxel segmentation difficult.

In this study, marrow content measurements compared to gold standard, variated less than 10% considering underestimation and overestimation. These values are lower than the 18% in overestimation and 15% in underestimation found by Liang[29] in a CBCT study measuring artificial periapical lesions. These differences could be explained because Liang measured volumes smaller than in our study. Goo,[30] Su[31] and Way,[32] using CT and evaluating simulated pulmonary nodules observed that accuracy is dependent on nodule size, obtaining more accurate measurements for larger volumes. Additionally, Kim[33] and Prionas[34] also obtained similar conclusions using simulated tumors. Marten[35] observed a greater tendency to underestimate nodule volume for the smaller ones. All these evidence could be a relevant information, since it states that smaller volume measurements are less accurate.

A CT study evaluating alveolar cleft[36] found errors ranging from 2.5% to 7.6%. In contrast, a study evaluating simulated defects[37] found lower volume errors of 2% and 0.4% using automated and manual volume measurements, respectively. In the unfilled specimen of the present study, volume measurements showed variation under

5%. Bayram,[38] measuring condyle volume in CBCT, found a tendency to overestimate or underestimate values, even without significant differences observed. Corroborating to these evidences, Liu,[27] measuring tooth volume, also observed that measurements slightly deviate from the physical volumes within -4% to 7%. Havercamp,[39] in a canine prostate volume study (water and soft tissue density), observed underestimated volume values in all situations when compared to physical gold standard. In the present study, marrow measurements obtained with ITK-SNAP were underestimated when compared to gold standard.

According to Kamburoglu,[22] accuracy of segmentation relies on the gray value and the threshold value entered by the operator. It could be a challenge to conduct segmentation when voxels of different structures have similar values. Fabel[40] also observed the same situation in segmenting lymph nodes adjacent to tissue of similar density. Maybe that's why it was felt some difficulty in segmenting the preserved marrow specimen, exactly because its voxel density was closer to bone density comparing to the other three contents. This difficulty was higher in ITK-SNAP software than in Dolphin, being more time consuming. However, besides ITK-SNAP measurements, in marrow content, were the least accurate measurements (with more than 5 % underestimation values) they were either the ones with the least variation.

Despite different CBCT systems can have different measurement results, even with the same voxel size, as observed by Sang[41] in a CBCT study, the present study also did not observe increased accuracy by increasing voxel resolution, since voxel size did not had a significant influence in volume measurements.

A recurrent problem in ITK-SNAP was that it frequently crashed while using, demanding to close it and reopen to allow segmentation. This could be related to the fact that it is an open source software (which is an advantage), while Dolphin needs a payed license to allow access to the software.

A limitation of the present study could be the fact that volume measurements were conduct by only one examiner. However, as it was obtained an almost perfect intraobserver reliability and a good interobserver reliability for unfilled specimen, it was decided that a second examiner was unnecessary. Additionally, also in a volume study, Pinsky[37] stated that reliability was obtained, despite the fact that examiners had no previous training in CT image analysis and that these results suggest that the methods are not examiner dependent.

In conclusion, content and software influences in volume measurements accuracy, especially when content has grey values close to that of the adjacent tissue. Unfilled specimens showed the most accurate volume values when compared to gold standard.

REFERENCES

1. Kragskov J, Bosch C, Gyldensted C, Sindet-Pedersen S. Comparison of the reliability of craniofacial anatomic landmarks based on cephalometric radiographs and three-dimensional CT scans. Cleft Palate Craniofac J. 1997 Mar;34(2):111–6.
2. Swennen GRJ, Schutyser F, Barth E-L, De Groeve P, De Mey A. A new method of 3-D cephalometry Part I: the anatomic Cartesian 3-D reference system. J Craniofac Surg. 2006 Mar;17(2):314–25.
3. Togashi K, Kitaura H, Yonetsu K, Yoshida N, Nakamura T. Three-dimensional cephalometry using helical computer tomography: measurement error caused by head inclination. Angle Orthod. 2002 Dec;72(6):513–20.
4. Swennen GRJ, Schutyser F. Three-dimensional cephalometry: spiral multi-slice vs cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2006 Sep;130(3):410–6.
5. Araki K, Maki K, Seki K, Sakamaki K, Harata Y, Sakaino R, et al. Characteristics of a newly developed dentomaxillofacial X-ray cone beam CT scanner (CB MercuRay™): System configuration and physical properties. Dentomaxillofacial Radiol. 2004;33(1):51–9.
6. Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA. A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. Eur Radiol. 1998;8(9):1558–64.
7. Miracle AC, Mukherji SK. Conebeam CT of the head and neck, part 2: clinical applications. AJNR Am J Neuroradiol. 2009 Aug;30(7):1285–92.
8. Hashimoto K, Arai Y, Iwai K, Araki M, Kawashima S, Terakado M. A comparison of a new limited cone beam computed tomography machine for dental use with a multidetector row helical CT machine. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2003;95(3):371–7.
9. Zinsly S dos R, Moraes LC de, Moura P de, Ursi W. Avaliação do espaço aéreo faríngeo por meio da tomografia computadorizada de feixe cônico. Vol. 15, Dental Press Journal of Orthodontics. 2010. p. 150–8.
10. Alsufyani NA, Noga ML, Witmans M, Cheng I, El-Hakim H, Major PW. Using cone beam CT to assess the upper airway after surgery in children with sleep disordered breathing symptoms and maxillary-mandibular disproportions: a clinical pilot. J Otolaryngol Head Neck Surg. 2017 Apr;46(1):31.
11. Wen X, Wang X, Qin S, Franchi L, Gu Y. Three-dimensional analysis of upper airway morphology in skeletal Class III patients with and without mandibular asymmetry. Angle Orthod. 2017 Jul;87(4):526–33.
12. Gupta J V, Makhija PG, Gupta KC. Does a correlation exist between nasal airway volume and craniofacial morphology: A cone beam computed tomography study. Indian J Dent Res. 2016;27(4):359–63.
13. Shahidi S, Momeni Danaie S, Omidi M. Comparison of the Pharyngeal Airway Volume between Non-Syndromic Unilateral Cleft Palate and Normal Individuals Using Cone Beam Computed Tomography. J Dent (Shiraz, Iran). 2016 Sep;17(3 Suppl):268–75.
14. Farzal Z, Walsh J, Lopes de Rezende Barbosa G, Zdanski CJ, Davis SD, Superfine R, et al. Volumetric nasal cavity analysis in children with unilateral and bilateral cleft lip and palate. Laryngoscope. 2016 Jun;126(6):1475–80.
15. Kamburoglu K, Yilmaz F, Gulsahi K, Gulen O, Gulsahi A. Change in Periapical

Lesion and Adjacent Mucosal Thickening Dimensions One Year after Endodontic Treatment: Volumetric Cone-beam Computed Tomography Assessment. J Endod. 2017 Feb;43(2):218–24.
16. Villoria EM, Lenzi AR, Soares R V, Souki BQ, Sigurdsson A, Marques AP, et al. Post-processing open-source software for the CBCT monitoring of periapical lesions healing following endodontic treatment: technical report of two cases. Dentomaxillofac Radiol. 2017 Jan;46(1):20160293.
17. de Rezende Barbosa GL, Wood JS, Pimenta LA, Maria de Almeida S, Tyndall DA. Comparison of different methods to assess alveolar cleft defects in cone beam CT images. Dentomaxillofac Radiol [Internet]. 2016;45(2):20150332. Available from: http://www.ncbi.nlm.nih.gov/pubmed/26648387
18. Zhou, W. N., Xu, Y. B., Jiang, H. B., Wan, L., & Du YF. Accurate Evaluation of Cone-Beam Computed Tomography to Volumetrically Assess Bone Grafting in Alveolar Cleft Patients. J Craniofac Surg [Internet]. 2015;26(6):e535–9. Available from: http://www.ncbi.nlm.nih.gov/pubmed/26355988
19. Lenza MG, Lenza MM de O, Dalstra M, Melsen B, Cattaneo PM. An analysis of different approaches to the assessment of upper airway morphology: a CBCT study. Orthod Craniofac Res. 2010 May;13(2):96–105.
20. Feng X, Li G, Qu Z, Liu L, Nasstrom K, Shi X-Q. Comparative analysis of upper airway volume with lateral cephalograms and cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2015 Feb;147(2):197–204.
21. Kasaven CP, Ivekovic S, McIntyre GT, Gillgrass T, Thomson DA, Menhinick A, et al. Validation of the volumetric measurement of a simulated maxillary alveolar bone defect using cone-beam computed tomography. Cleft Palate-Craniofacial J [Internet]. 2013;50(6):e115–20. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84888596061&doi=10.1597%2F12-161&partnerID=40&md5=380b6e0ff9616981e07af90e239a7367
22. Kamburoglu K, Kursun S, Kilic C, Ozen T. Accuracy of virtual models in the assessment of maxillary defects. Imaging Sci Dent. 2015 Mar;45(1):23–9.
23. Albuquerque MAP, Gaia BF, Cavalcanti MGP. Oral cleft volumetric assessment by 3D multislice computed tomographic images. Int J Oral Maxillofac Surg [Internet]. 2011;40(11):1280–8. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-82955203381&doi=10.1016%2Fj.ijom.2011.05.015&partnerID=40&md5=d63eee0d4fe77c915e77647d19c41b09
24. Amirlak B, Tang CJ, Becker D, Palomo JM, Gosain AK, B. A, et al. Volumetric analysis of simulated alveolar cleft defects and bone grafts using cone beam computed tomography. Plast Reconstr Surg [Internet]. 2013;131(4):854–9. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L368976022
25. Yushkevich PA, Piven J, Hazlett HC, Smith RG, Ho S, Gee JC, et al. User-guided 3D active contour segmentation of anatomical structures: significantly improved efficiency and reliability. Neuroimage. 2006 Jul;31(3):1116–28.
26. Yushkevich PA, Pashchinskiy A, Oguz I, Mohan S, Schmitt JE, Stein JM, et al. User-Guided Segmentation of Multi-modality Medical Imaging Datasets with ITK-SNAP. Neuroinformatics. 2019;17(1):83–102.
27. Liu Y, Olszewski R, Alexandroni ES, Enciso R, Xu T, Mah JK, et al. The validity of in vivo tooth volume determinations from cone-beam computed tomography.

Angle Orthod [Internet]. 2010;80(1):160–6. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L355618748

28. Whyms BJ, Vorperian HK, Gentry LR, Schimek EM, Bersu ET, Chung MK, et al. The effect of computed tomographic scanner parameters and 3-dimensional volume rendering techniques on the accuracy of linear, angular, and volumetric measurements of the mandible. Oral Surg Oral Med Oral Pathol Oral Radiol [Internet]. 2013;115(5):682–91. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L368780625
29. Liang Y-H, Jiang L, Gao X-J, Shemesh H, Wesselink PR, Wu M-K, et al. Detection and measurement of artificial periapical lesions by cone-beam computed tomography. Int Endod J [Internet]. 2014;47(4):332–8. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L608094882
30. Goo JM, Tongdee T, Tongdee R, Yeo K, Hildebolt CF, Bae KT. Volumetric measurement of synthetic lung nodules with multi-detector row CT: Effect of various image reconstruction parameters and segmentation thresholds on measurement accuracy. Radiology [Internet]. 2005;235(3):850–6. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-18844382442&doi=10.1148%2Fradiol.2353040737&partnerID=40&md5=46f069a5ccd415eeda89b71b331a9984
31. Su D, Feng L, Jiang Y WY. Effect of scanning and reconstruction parameters on three dimensional volume and CT value measurement of pulmonary nodules: A phantom study. Chinese J Lung Cancer [Internet]. 2017;20(8):562–7. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L619279157
32. Way TW, Chan HP, Goodsitt MM, Sahiner B, Hadjiiski LM, Zhou C CA. Effect of CT scanning parameters on volumetric measurements of pulmonary nodules by 3D active contour segmentation: A phantom study. Phys Med Biol [Internet]. 2008;53(5):1295–312. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L351594427
33. Kim H-S, Wang J-H, Lim I-H, Park K-T, Yeon S-C, Lee H-C. Three-dimensional volume assessment accuracy in computed tomography using a phantom. J Vet Clin [Internet]. 2013;30(4):268–72. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84885214839&partnerID=40&md5=8bdb91ba80958dd87552de66d35071a1
34. Prionas ND, Ray S, Boone JM. Volume assessment accuracy in computed tomography: a phantom study. J Appl Clin Med Phys [Internet]. 2010;11(2):3037. Available from: http://www.ncbi.nlm.nih.gov/pubmed/20592693
35. Marten K, Dullin C, Machann W, Schmid JS, DAS M, Hermann KP EC. Comparison of flat-panel-detector-based CT and multidetector-row CT in automated volumetry of pulmonary nodules using an anthropomorphic chest phantom. Br J Radiol [Internet]. 2009;82(981):716–23. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L355267632
36. Kobayashi Y, Satoh K, Kanamori D, Mizutani H, Fujii N, Aizawa T, et al. Evaluating the exposure dose of 320-row area detector computed tomography

and its reliability in the measurement of bone defect in alveolar cleft. J Oral Maxillofac Surgery, Med Pathol [Internet]. 2017 Jul;29(4):350–7. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85017377882&doi=10.1016%2Fj.ajoms.2017.03.006&partnerID=40&md5=1b4b105a2a0553755f46198d1b8ad516

37. Pinsky HM, Dyda S, Pinsky RW, Misch KA, Sarment DP, H.M. P, et al. Accuracy of three-dimensional measurements using cone-beam CT. Dentomaxillofacial Radiol [Internet]. 2006;35(6):410–6. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L44904797
38. Bayram M, Kayipmaz S, Sezgin OS, Küçük M. Volumetric analysis of the mandibular condyle using cone beam computed tomography. Eur J Radiol [Internet]. 2012;81(8):1812–6. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21680124
39. Haverkamp K, Harder LK, Kuhnt NSM, Lupke M, Nolte I, Wefstaedt P. Validation of canine prostate volumetric measurements in computed tomography determined by the slice addition technique using the Amira program. BMC Vet Res. 2019 Feb;15(1):49.
40. M. Fabel, J. Biederer, A. Jochens, L. Bornemann, G. Soza, M. Heller HB. Semi-automated volumetric analysis of artificial lymph nodes in a phantom study. Eur J Radiol [Internet]. 2011;80(3):e451–7. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L51157907
41. Sang Y-H, Hu H-C, Lu S-H, Wu Y-W, Li W-R, Tang Z-H. Accuracy Assessment of Three-dimensional Surface Reconstructions of In vivo Teeth from Cone-beam Computed Tomography. Chin Med J (Engl). 2016 Jun;129(12):1464–70.

5 CONSIDERAÇÕES FINAIS

Estudos *in vitro* são necessários para a validação de medidas, permitindo a comparação com medidas físicas reais, o que normalmente não é possível em estudos clínicos. A revisão sistemática, utilizando estudos *in vitro*, demonstrou que, em geral, medidas de volume em imagens de tomografia computadorizada costumam ser acuradas quando comparadas ao volume físico. Porém, alguns estudos encontraram medidas acuradas dependendo de determinadas situações, como o tamanho da estrutura mensurada ou do protocolo utilizado na aquisição das imagens.

Além disso, cada equipamento possui características peculiares e geralmente não existe uma calibração específica recomendada ou padronização na utilização de parâmetros tais como: quilovoltagem (kV), miliamperagem (mA) e tamanho de voxel. Os softwares de medidas disponíveis, tanto de acesso livre quanto os que necessitam aquisição de uma licença para utilização, também utilizam formas diversas de medição de volume.

A revisão sistemática evidenciou a falta de estudos comparando estruturas de diferentes densidades. Dessa forma, a realização do estudo experimental foi de extrema importância. A comparação do volume de preenchimentos de diferentes densidades com a medida física, considerada padrão ouro, mostrou que o conteúdo pode interferir na medida de volume, independente do software escolhido ou do tamanho de voxel utilizado na aquisição das imagens. Isso acontece especialmente em situações em que a densidade da estrutura medida aproxima-se da densidade da estrutura contígua, dificultando a segmentação. A limitação desse estudo deve-se ao fato de serem medidas obtidas em situações clínicas simuladas, tentando aproximar-se de situações clínicas reais.

Assim, sabendo-se que medidas de volume obtidas em situações simuladas podem ser consideradas acuradas, essa informação deve ser utilizada com cautela na tentativa de extrapolação para situações clínicas.

REFERÊNCIAS

1. White SC; Pharoah MJ. Radiologia oral: fundamentos e interpretação. 5 ed. Rio de Janeiro: Elsevier; 2007. 724 p.
2. Delamare EL, Liedke GS, Vizzotto MB, da Silveira HLD, Ribeiro JLD, Silveira HED. Influence of a programme of professional calibration in the variability of landmark identification using cone beam computed tomography-synthesized and conventional radiographic cephalograms. Dentomaxillofac Radiol. 2010 Oct;39(7):414–23.
3. Silveira HLD, Gomes MJ, Silveira HED, Dalla-Bona RR. Evaluation of the radiographic cephalometry learning process by a learning virtual object. Am J Orthod Dentofacial Orthop. 2009 Jul;136(1):134–8.
4. Silveira HLD, Silveira HED, Dalla-Bona RR, Abdala DD, Bertoldi RF, von Wangenheim A. Software system for calibrating examiners in cephalometric point identification. Am J Orthod Dentofacial Orthop. 2009 Mar;135(3):400–5.
5. Kragskov J, Bosch C, Gyldensted C, Sindet-Pedersen S. Comparison of the reliability of craniofacial anatomic landmarks based on cephalometric radiographs and three-dimensional CT scans. Cleft Palate Craniofac J. 1997 Mar;34(2):111–6.
6. Swennen GRJ, Schutyser F, Barth E-L, De Groeve P, De Mey A. A new method of 3-D cephalometry Part I: the anatomic Cartesian 3-D reference system. J Craniofac Surg. 2006 Mar;17(2):314–25.
7. Togashi K, Kitaura H, Yonetsu K, Yoshida N, Nakamura T. Three-dimensional cephalometry using helical computer tomography: measurement error caused by head inclination. Angle Orthod. 2002 Dec;72(6):513–20.
8. Swennen GRJ, Schutyser F. Three-dimensional cephalometry: spiral multi-slice vs cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2006 Sep;130(3):410–6.
9. Araki K, Maki K, Seki K, Sakamaki K, Harata Y, Sakaino R, et al. Characteristics of a newly developed dentomaxillofacial X-ray cone beam CT scanner (CB MercuRay™): System configuration and physical properties. Dentomaxillofacial Radiol. 2004;33(1):51–9.
10. Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA. A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary

results. Eur Radiol. 1998;8(9):1558–64.

11. Miracle AC, Mukherji SK. Conebeam CT of the head and neck, part 2: clinical applications. AJNR Am J Neuroradiol. 2009 Aug;30(7):1285–92.
12. Holberg C, Steinhauser S, Geis P, Rudzki-Janson I. Cone-beam computed tomography in orthodontics: benefits and limitations. J Orofac Orthop. 2005 Nov;66(6):434–44.
13. Scarfe WC, Farman AG, Sukovic P. Clinical applications of cone-beam computed tomography in dental practice. J Can Dent Assoc. 2006 Feb;72(1):75–80.
14. Razi T, Niknami M, Alavi Ghazani F. Relationship between Hounsfield Unit in CT Scan and Gray Scale in CBCT. J Dent Res Dent Clin Dent Prospects. 2014;8(2):107–10.
15. Pauwels R, Nackaerts O, Bellaiche N, Stamatakis H, Tsiklakis K, Walker A, et al. Variability of dental cone beam CT grey values for density estimations. Br J Radiol. 2013 Jan;86(1021):20120135.
16. Pauwels R, Jacobs R, Singer SR, Mupparapu M. CBCT-based bone quality assessment: are Hounsfield units applicable? Dentomaxillofac Radiol. 2015;44(1):20140238.
17. Magill D, Beckmann N, Felice MA, Yoo T, Luo M, Mupparapu M. Investigation of dental cone-beam CT pixel data and a modified method for conversion to Hounsfield unit (HU). Dentomaxillofac Radiol. 2018 Feb;47(2):20170321.
18. Pauwels R, Araki K, Siewerdsen JH, Thongvigitmanee SS. Technical aspects of dental CBCT: state of the art. Dentomaxillofac Radiol. 2015;44(1):20140224.
19. Hatcher DC. Cone beam computed tomography: craniofacial and airway analysis. Dent Clin North Am. 2012 Apr;56(2):343–57.
20. Gibbs SJ. Effective dose equivalent and effective dose: comparison for common projections in oral and maxillofacial radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2000 Oct;90(4):538–45.
21. Ludlow JB, Davies-Ludlow LE, Brooks SL. Dosimetry of two extraoral direct digital imaging devices: NewTom cone beam CT and Orthophos Plus DS panoramic unit. Dentomaxillofac Radiol. 2003 Jul;32(4):229–34.
22. Farman AG. ALARA still applies. Vol. 100, Oral surgery, oral medicine, oral pathology, oral radiology, and endodontics. United States; 2005. p. 395–7.
23. Winter AA, Pollack AS, Frommer HH, Koenig L. Cone beam volumetric

tomography vs. medical CT scanners. N Y State Dent J. 2005;71(4):28–33.

24. Jaju PP, Jaju SP. Cone-beam computed tomography: Time to move from ALARA to ALADA. Imaging Sci Dent. 2015 Dec;45(4):263–5.
25. Gribel BF, Gribel MN, Frazao DC, McNamara JAJ, Manzi FR. Accuracy and reliability of craniometric measurements on lateral cephalometry and 3D measurements on CBCT scans. Angle Orthod. 2011 Jan;81(1):26–35.
26. Liu Y, Olszewski R, Alexandroni ES, Enciso R, Xu T, Mah JK, et al. The validity of in vivo tooth volume determinations from cone-beam computed tomography. Angle Orthod [Internet]. 2010;80(1):160–6. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L355618748
27. da Silveira PF, Vizzotto MB, Liedke GS, da Silveira HLD, Montagner F, da Silveira HED. Detection of vertical root fractures by conventional radiographic examination and cone beam computed tomography - an in vitro analysis. Dent Traumatol. 2013 Feb;29(1):41–6.
28. Liedke GS, da Silveira HED, da Silveira HLD, Dutra V, de Figueiredo JAP. Influence of voxel size in the diagnostic ability of cone beam tomography to evaluate simulated external root resorption. J Endod. 2009 Feb;35(2):233–5.
29. Hutchinson JC, Shelmerdine SC, Simcock IC, Sebire NJ, Arthurs OJ. Early clinical applications for imaging at microscopic detail: microfocus computed tomography (micro-CT). Br J Radiol. 2017 Jul;90(1075):20170113.
30. Zinsly S dos R, Moraes LC de, Moura P de, Ursi W. Avaliação do espaço aéreo faríngeo por meio da tomografia computadorizada de feixe cônico. Vol. 15, Dental Press Journal of Orthodontics. 2010. p. 150–8.
31. Alsufyani NA, Noga ML, Witmans M, Cheng I, El-Hakim H, Major PW. Using cone beam CT to assess the upper airway after surgery in children with sleep disordered breathing symptoms and maxillary-mandibular disproportions: a clinical pilot. J Otolaryngol Head Neck Surg. 2017 Apr;46(1):31.
32. Wen X, Wang X, Qin S, Franchi L, Gu Y. Three-dimensional analysis of upper airway morphology in skeletal Class III patients with and without mandibular asymmetry. Angle Orthod. 2017 Jul;87(4):526–33.
33. Gupta J V, Makhija PG, Gupta KC. Does a correlation exist between nasal airway volume and craniofacial morphology: A cone beam computed tomography study. Indian J Dent Res. 2016;27(4):359–63.

34. Shahidi S, Momeni Danaie S, Omidi M. Comparison of the Pharyngeal Airway Volume between Non-Syndromic Unilateral Cleft Palate and Normal Individuals Using Cone Beam Computed Tomography. J Dent (Shiraz, Iran). 2016 Sep;17(3 Suppl):268–75.
35. Farzal Z, Walsh J, Lopes de Rezende Barbosa G, Zdanski CJ, Davis SD, Superfine R, et al. Volumetric nasal cavity analysis in children with unilateral and bilateral cleft lip and palate. Laryngoscope. 2016 Jun;126(6):1475–80.
36. Kamburoglu K, Yilmaz F, Gulsahi K, Gulen O, Gulsahi A. Change in Periapical Lesion and Adjacent Mucosal Thickening Dimensions One Year after Endodontic Treatment: Volumetric Cone-beam Computed Tomography Assessment. J Endod. 2017 Feb;43(2):218–24.
37. Villoria EM, Lenzi AR, Soares R V, Souki BQ, Sigurdsson A, Marques AP, et al. Post-processing open-source software for the CBCT monitoring of periapical lesions healing following endodontic treatment: technical report of two cases. Dentomaxillofac Radiol. 2017 Jan;46(1):20160293.
38. de Rezende Barbosa GL, Wood JS, Pimenta LA, Maria de Almeida S, Tyndall DA. Comparison of different methods to assess alveolar cleft defects in cone beam CT images. Dentomaxillofac Radiol [Internet]. 2016;45(2):20150332. Available from: http://www.ncbi.nlm.nih.gov/pubmed/26648387
39. Zhou, W. N., Xu, Y. B., Jiang, H. B., Wan, L., & Du YF. Accurate Evaluation of Cone-Beam Computed Tomography to Volumetrically Assess Bone Grafting in Alveolar Cleft Patients. J Craniofac Surg [Internet]. 2015;26(6):e535–9. Available from: http://www.ncbi.nlm.nih.gov/pubmed/26355988
40. Ge Z pu, Ma R han, Li G, Zhang J zong, Ma X chen. Age estimation based on pulp chamber volume of first molars from cone-beam computed tomography images. Forensic Sci Int. 2015;253:133.e1-133.e7.
41. Forst D, Nijjar S, Flores-Mir C, Carey J, Secanell M, Lagravere M. Comparison of in vivo 3D cone-beam computed tomography tooth volume measurement protocols. Prog Orthod. 2014;15:69.
42. Hashimoto K, Arai Y, Iwai K, Araki M, Kawashima S, Terakado M. A comparison of a new limited cone beam computed tomography machine for dental use with a multidetector row helical CT machine. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2003;95(3):371–7.
43. Ohkubo M, Sano T, Otonari-Yamamoto M, Hayakawa Y, Okano T, Sakurai K, et

al. Magnetic resonance signal intensity from retrodiscal tissue related to joint effusion status and disc displacement in elderly patients with temporomandibular joint disorders. Bull Tokyo Dent Coll [Internet]. 2009 May [cited 2019 Jul 15];50(2):55–62. Available from: http://www.ncbi.nlm.nih.gov/pubmed/19815992

44. Guijarro-Martínez R, Swennen GRJ. Cone-beam computerized tomography imaging and analysis of the upper airway: a systematic review of the literature. Int J Oral Maxillofac Surg [Internet]. 2011 Nov [cited 2019 Jul 15];40(11):1227–37. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21764260
45. Lenza MG, Lenza MM de O, Dalstra M, Melsen B, Cattaneo PM. An analysis of different approaches to the assessment of upper airway morphology: a CBCT study. Orthod Craniofac Res. 2010 May;13(2):96–105.
46. Feng X, Li G, Qu Z, Liu L, Nasstrom K, Shi X-Q. Comparative analysis of upper airway volume with lateral cephalograms and cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2015 Feb;147(2):197–204.
47. Aboudara C, Nielsen I, Huang JC, Maki K, Miller AJ, Hatcher D. Comparison of airway space with conventional lateral headfilms and 3-dimensional reconstruction from cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2009 Apr;135(4):468–79.
48. Kasaven CP, Ivekovic S, McIntyre GT, Gillgrass T, Thomson DA, Menhinick A, et al. Validation of the volumetric measurement of a simulated maxillary alveolar bone defect using cone-beam computed tomography. Cleft Palate-Craniofacial J [Internet]. 2013;50(6):e115–20. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84888596061&doi=10.1597%2F12-161&partnerID=40&md5=380b6e0ff9616981e07af90e239a7367
49. Kamburoglu K, Kursun S, Kilic C, Ozen T. Accuracy of virtual models in the assessment of maxillary defects. Imaging Sci Dent. 2015 Mar;45(1):23–9.
50. Dong T, Xia L, Cai C, Yuan L, Ye N, Fang B. Accuracy of in vitro mandibular volumetric measurements from CBCT of different voxel sizes with different segmentation threshold settings. BMC Oral Health. 2019 Sep;19(1):206.
51. Chen H, van Eijnatten M, Wolff J, de Lange J, van der Stelt PF, Lobbezoo F, et al. Reliability and accuracy of three imaging software packages used for 3D analysis of the upper airway on cone beam computed tomography images. Dentomaxillofac Radiol. 2017 Aug;46(6):20170043.

52. Ahlowalia MS, Patel S, Anwar HMS, Cama G, Austin RS, Wilson R, et al. Accuracy of CBCT for volumetric measurement of simulated periapical lesions. Int Endod J [Internet]. 2013;46(6):538–46. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23216253

53. Wang Y, He S, Yu L, Li J, Chen S. Accuracy of volumetric measurement of teeth in vivo based on cone beam computer tomography. Orthod Craniofacial Res [Internet]. 2011;14(4):206–12. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-80054835358&doi=10.1111%2Fj.1601-6343.2011.01525.x&partnerID=40&md5=75c47096196836b9cbcd98563db2036e

54. Whyms BJ, Vorperian HK, Gentry LR, Schimek EM, Bersu ET, Chung MK, et al. The effect of computed tomographic scanner parameters and 3-dimensional volume rendering techniques on the accuracy of linear, angular, and volumetric measurements of the mandible. Oral Surg Oral Med Oral Pathol Oral Radiol [Internet]. 2013;115(5):682–91. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L368780625

55. Agbaje JO, Jacobs R, Maes F, Michiels K, van Steenberghe D, J.O. A, et al. Volumetric analysis of extraction sockets using cone beam computed tomography: a pilot study on ex vivo jaw bone. J Clin Periodontol [Internet]. 2007;34(11):985–90. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L47574499

56. Pinsky HM, Dyda S, Pinsky RW, Misch KA, Sarment DP, H.M. P, et al. Accuracy of three-dimensional measurements using cone-beam CT. Dentomaxillofacial Radiol [Internet]. 2006;35(6):410–6. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L44904797

57. Esposito, S.A., Huybrechts, B., Slagmolen, P., Cotti, E., Coucke, W., Pauwels, R., Lambrechts, P., and Jacobs R. A novel method to estimate the volume of bone defects using cone-beam computed tomography: an in vitro study. J Endod [Internet]. 2013;39(9):1111–5. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23953281

58. Abdelhamid A, Omran M, Bakhshalian N, Tarnow D, Zadeh HH. An open randomized controlled clinical trial to evaluate ridge preservation and repair using SocketKAP() and SocketKAGE() : part 2 - three-dimensional alveolar bone volumetric analysis of CBCT imaging. Clin Oral Implants Res. 2016 Jun;27(6):631–9.
59. Saccucci M, Polimeni A, Festa F, Tecco S. Do skeletal cephalometric characteristics correlate with condylar volume, surface and shape? A 3D analysis. Head Face Med. 2012;8(1).
60. Bernades-Mayordomo R, Guijarro-Martínez R, Hernández-Alfaro F. Volumetric CBCT analysis of the palatine process of the anterior maxilla: A potential source for bone grafts. Int J Oral Maxillofac Surg [Internet]. 2013 Mar [cited 2019 Jul 15];42(3):406–10. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23062715
61. Ohe JY, Kim GT, Lee JW, Al Nawas B, Jung J, Kwon YD. Volume stability of hydroxyapatite and β-tricalcium phosphate biphasic bone graft material in maxillary sinus floor elevation: A radiographic study using 3D cone beam computed tomography. Clin Oral Implants Res. 2016;27(3):348–53.
62. Berberi A, Bouserhal L, Nader N, Assaf RB, Nassif NB, Bouserhal J, et al. Evaluation of Three-Dimensional Volumetric Changes After Sinus Floor Augmentation with Mineralized Cortical Bone Allograft. J Maxillofac Oral Surg. 2015;14(3):624–9.
63. Klein GBG, Curvello VP, Dutra RA, Simeão SP, Santos PL, Gulinelli JL, et al. Bone volume changes after sinus floor augmentation with heterogenous graft. Int J Oral Maxillofac Implants [Internet]. 2016;31(3):665–71. Available from: http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L615817741
64. Altug HA, Coskun AT, Kamburoglu K, Zerener T, Gulen O, Sencimen M, et al. Volumetric Evaluation of Safe Zone for Bone Harvesting from Symphysis Region by Using Cone Beam Computed Tomography. Implant Dent. 2016;25(6):758–61.
65. Goulart DR, Muñoz P, Cantín López MG, de Moraes M, Olate S. Comparative Evaluation of Condylar Volume Between Patients With Unilateral Condylar Hyperplasia and Class III Dentofacial Deformity. J Oral Maxillofac Surg. 2017;75(1):180–8.

ANEXO A – PROJETO DE PESQUISA PARA DESENVOLVIMENTO DO ESTUDO-PILOTO.

Dados Gerais:

Projeto Nº:	29770	**Título:**	VALIDACAO DE MEDICOES DE VOLUME EM IMAGENS DE TOMOGRAFIA COMPUTADORIZADA DE FEIXE CONICO – ESTUDO EXPERIMENTAL IN VITRO		
Área de conhecimento:	Radiologia Odontológica	**Início:**	01/10/2015	**Previsão de conclusão:**	31/12/2018
Situação:	Projeto em Andamento				
Origem:	Faculdade de Odontologia Departamento de Cirurgia e Ortopedia		**Projeto Isolado com linha temática:** Diagnóstico das Afecções Buco-faciais		
Local de Realização:	não informado				

Não apresenta relação com Patrimônio Genético ou Conhecimento Tradicional Associado.

Objetivo:

As tomografias computadorizadas são exames de grande precisão utilizados para planejamento e diagnóstico em Odontologia, mas que nem sempre estão ao alcance do paciente, e, portanto do cirurgião-dentista. O desenvolvimento de tomógrafos computadorizados de feixe cônico permitiu exames tomográficos com menor exposição do paciente à radiação, mais rápidos e de menor custo, tornando estes mais acessíveis à população e com aplicabilidade em diversas áreas da odontologia.

Palavras Chave:

ESPAÇO AÉREO, DIAGNÓSTICO POR IMAGEM, TCFC

Equipe UFRGS:

Nome: MARIANA BOESSIO VIZZOTTO
Coordenador - Início: 01/10/2015 Previsão de término: 31/12/2018

Nome: HELOISA EMILIA DIAS DA SILVEIRA
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Nome: Michele Machado Vidor
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Nome: NÁDIA ASSEIN ARÚS
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Avaliações:

Comissão de Pesquisa de Odontologia - **Aprovado** em 17/08/2015 Clique aqui para visualizar o parecer

ANEXO B – DECLARAÇÃO DE COLABORAÇÃO PARA REALIZAÇÃO DA ETAPA LABORATORIAL NO LABORATÓRIO DE PROCESSAMENTO DE IMAGEM DIGITAL DA FACULDADE DE ODONTOLOGIA DA UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL

UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
FACULDADE DE ODONTOLOGIA
LABORATÓRIO DE PROCESSAMENTO DE IMAGEM DIGITAL

Porto Alegre, 26 de julho de 2017.

Prezados Senhores,

RE: **"MEDIÇÕES DE VOLUME EM IMAGENS DE TOMOGRAFIA COMPUTADORIZADA DE FEIXE CÔNICO – REVISÃO SISTEMÁTICA DA LITERATURA E ESTUDO EXPERIMENTAL IN VITRO"**

Informo que será disponibilizada a área física do Laboratório de Processamento de Imagem Digital (LAPID) da Faculdade de Odontologia da Universidade Federal do Rio Grande do Sul e seu parque de equipamentos para a execução do projeto de pesquisa. O laboratório apresenta os equipamentos necessários para a reconstrução e processamento das imagens por meio de softwares específicos.

Acredito que esta será uma experiência enriquecedora para a Faculdade de Odontologia, especialmente para os docentes e alunos envolvidos no projeto.

Prof. Dr. Heraldo Luís Dias da Silveira
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