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Accuracy of Linear Measurement in Computed Tomography: A Systematic Review

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ABSTRACT

Objective: The aim of this study was to identify, from a systematic review of the literature, whether two-dimensional images (2D) generated by computed tomography (CT) and processed by multiplanar reformatting software are accurate for planning dental treatments.

Methods: We performed a systematic search of PubMed, Medline, Science Direct and VHL. It was included the articles that met the selection criteria: evaluation of CT scan of the skull using reformatting 2D images (DICOM); articles published from and including 2008; studies with human skull; linear measurements between reference points; results obtained by comparing direct measurements in skull and on 2D images.

Results: Sixteen studies met the criteria. The reformatting softwares were used to obtain transverse cross-sectional, axial, coronal, sagital or cephalometric images obtained from human skull by CT scanners. The studies compared direct with virtual measurements, using different CT scanners. They were evaluated reference points identified with radiopaque material or not. In some studies the protocols were modified and compared with gold standard to evaluate the possible interference in the accuracy of reformatted images.

Conclusions: The systematic literature analisys validated the linear measurements between different bony landmarks as accurated on reformatted CBCT images. Few studies evaluated the images of multslice CT. There was a lack of standardization in the methodologies, great variety of CT scanners and CT reformatting software, all these factors made difficult to compare results obtained in the studies.

Keywords: computerized tomography; multiplanar reconstructions.

INTRODUCTION

The accuracy in the diagnosis and treatment planning of patients is a challenge for dentists and for a long time only conventional radiographs were used. With the development of more sophisticated techniques as computed tomography (CT), widely used in the medical field, CT has become increasingly important in treatment planning and diagnosis in implant Dentistry, among other things. [1,2] Images of soft and hard tissues of the head and neck and the images can be processed in specific software generating two-dimensional images (2D) (panoramic, lateral, axial, sagittal, coronal and cross-sectional) or three-dimensional (3D) images.[3]

The multi-planar reformatting (MPR) softwares have been successfully applied in the areas of surgery, implantology and orthodontics. The CT scanners provide high quality and more accurate images than conventional radiographs nevertheless the effects of postprocessing on the image quality are little discussed throughout literature. CT allows for the reproduction of a section of the human body in any of the three spatial planes: axial, sagittal and coronal.[2,4] The equipment can be divided into two categories based on the acquisition geometry of the X-ray beam, ie the Fan /Helical CT and Cone Beam CT (CBCT), developed especially for the dental field. The helical technology initially performed with scanners of a single line of detectors, has been replaced by scanners of multiple line detectors, multislice CT (MCT). Additionally there are different softwares on the market able to process and analyze the images obtained by CT, generating 2D and 3D images. The 2D and 3D images have been studied for diagnostic possibilities but little information exists about their validity in linear accuracy and reliability. Accuracy of the measurement is related to real dimension approaching the actual size of the object studied. This means that the measurements made directly on the skull or CT image in the same skull are absolutely similar or accuracy and reproducibility of the method is confirmed

before few errors in the repetition of the measurements both intra and inter-examiner.[2] This systematic review evaluated the accuracy of 2D images generated by different scanners and processed by refRMP software RMP, trying to determine whether the method can be applied in the planning of dental treatments.

MATERIAL AND METHODS

This study is a systematic review to what following question was done: "The 2D images generated by CT scanners and processed by software MPR are accurate for planning dental treatments"? It was searched the databases MEDLINE, PubMed, ScienceDirect and VHL / BIREME and all articles published between 2008 and 2013 were included in the search. The following keywords were included: "accuracy in computed tomography" and "multiplanar reconstruction." The selection was limited to human studies and included articles written in English (Table 1). The eligibility of the selected studies was determined by reading the abstracts of the articles found in the databases. After the abstract readings, the following inclusion criteria were established to select the proper papers:

- Evaluation of 2D reformation images (DICOM) of CT Skull;
- Articles published from 2008;
- Studies with human skull;
- Accuracy of linear measurements between reference points;
- Results obtained by comparing the (gold standard) direct measurements on skulls and CT images;
- Gold standard measurements performed on human skull.

All abstracts that met the above inclusion criteria were included in the review after selection by two independent reviewers. Whenever there was a discrepancy between the reviewers a final decision was made in consensus. If the information provided by the abstract were not clear for decision taking, the full article was retrieved, read and then the decision was made. The full manuscripts of the selected abstracts were retrieved and assessed independently by the two reviewers and a consensus was reached regarding which articles fulfilled all inclusion criteria and these were included in the final systematic review to analyze the data.

RESULTS

The keyword "Multiplanar Reconstruction" using the “PubMed database” and filters “publications in the last five years”, “English language” had 165 references and abstracts from those one abstract was selected and the correspondent full article. In the “Medline” using filter “English”, 838 references was found, one abstract and the correspondent full article was selected. The search on ScienceDirect was conducted from 2008 to 2013, 3,766 references were found, but none of the abstracts was selected and from VHL / BIREME database, was retrieved 594 references but none of the abstracts were selected (Table 1).

Table 1 – Estrategies of search and number of articles found in database

Database	Estrategies of search (2008 - 2013)	Nº of abstracts found	Nº of selected abstracts	Nº of articles found	Articles included
PubMed	(1) multiplanar reconstruction; (2) accuracy in computed tomography; (3) 1 or 2; (4) 1 and 2	(1) 165 (2) 5.045	(1) 1 (2) 35	(1) 1 (2) 30	(1) - (2) 15
Medline	(1) multiplanar reconstruction; (2) accuracy in computed tomography; (3) 1 or 2; (4) 1 and 2;	(1) 838 (2) 5.360	(1) 1 (2) 26	(1) 1 (2) 21	(1) - (2) 10
Science Direct/CAPES	(1) multiplanar reconstruction; (2) accuracy in computed tomography; (3) 1 or 2; (4) 1 and 2	(1)3.766 (2) 1.000	(1) 0 (2) 15	(1) - (2) 15	(1) - (2) 6
BVS BIREME	(1) multiplanar reconstruction; (2) accuracy in computed tomography; (3) 1 or 2; (4) 1 and 2	(1) 594 (2) 2.530	(1) 0 (2) 2	(1) - (2) 1	(1) - (2) -
Total				40	16

The keyword " Accuracy on Computed Tomography ", using filters, PubMed, publications in the last five years and English language showed 5,045 entries. It was selected 35 abstracts and 30 full papers. The filters Medline and English, retrieved 5,360 references. It was selected 26 abstracts and 22 full papers. The filters ScienceDirect from 2008 to 2013, retrieved 1,000 references. It was selected 16 abstracts and all correspondent full articles. The filters VHL / BIREME retrieved 2,530 articles. It was selected two abstracts and one full article (Table 1). The abstracts online search retrieved 40 full articles which were analyzed by the two reviewers. From these 40 articles, the reviewers selected the articles that met the inclusion criteria according to the methodology described on the papers. From the 40 articles, 24 were excluded [5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,20], 13 articles used linear measurements on 3D reconstructions[6,7,8,10,11,12,14,16,18, 21, 22, 27,28], 5 studies in animals[9, 12, 24, 25, 26], 4 radiopaque markers[13,15,17,23], 1 no methodology described[19], 1 images were not in DICOM format[29] and 1 the measurements were in teeth inserted in soft material.[20] So, the final selection produced a total of 16 articles (Table 1). An individual analysis of the final 16 articles, in chronological order, (Table 2) was performed.

Study	Objective of the study	Type of CT	Reformatting Software	Results
Veyre-Goulet et al.[30]	Evaluate the accuracy of linear measurements provided by CBCT in posterior maxilla.	CBCT (NewTom 9000®, Verona, Italy)	EasyGuide®, Keystone Dental, Inc., Burlington, MA, EUA	Clinical analysis demonstrated no difference between real measurements and image measurements.
Suomalainen et al.[31]	Evaluate the accuracy of linear measurements obtained with dental CBCT and MSCT by altering radiation doses using pre-operative planning of the placement of oral implants as a model.	CBCT (3D Accuitomo®, J Morita MFG. Corp., Kyoto, Japão)	DentaScan®, GE Medical Systems, Waukesha, WI, EUA	The measurement error (ME) showed significant differences between the methods studied (P = 0.022): the mean ME was 4.7% for CBCT and 8.8% for MSCT of the dry mandible, 2.3% and 6.6%, respectively, for the mandible immersed in sucrose solution and 5.4% for low-dose MSCT. Lowering the MSCT radiation dose to less than a quarter of its conventional original value did not significantly affect the ME.
		MSCT 4 slices (LightSpeed Plus®, GE Medical Systems, Waukesha, WI, EUA)	DentaScan®, GE Medical Systems, Waukesha, WI, EUA	
Gahleitner et al.[32]	Determine the accuracy of crown diameter measurements dy dental CT as a tool for preoperative diagnosis before tooth transplantations.	CBCT (Tomoscan SR-6000®, Philips Medical Systems, Best, Holanda)	Dental software package 2.1, Philips Medical Systems, Best, The Netherlands	Bucco-lingual measurements = There was no significant difference between the CT and clinical measurements (P = 0.19). On average, the CT measurements were 0.96% higher than the clinical measurements for the buco-lingual diameter. Mesio-distal measurements = CT shows underestimated values compared to clinical measurements (P= 0.0012). For the mesio-distal diameter , the CT measurements were 2.32% lower.
Kamburoglu et al.[33]	Asses the accuracy and reproducibility of CBCT measurements of specific distances around the mandibular canal by comparing them to direct digital caliper measurements.	TCFC (Iluma®, Imtec Imaging, 3M Health Care, Ardmore, OK, EUA)	Iluma Dental Imaging®, Imtec Imaging, 3M Health Care, Ardmore, OK, EUA	Intraobserver and interobserver measurements for all distances showed high agreement. The intraclass correlation coeficients (ICC) for CBCT and direct digital caliper ranged from 0.61 to 0.93 for the first observer and from 0.40 to 0.95 for the second observer. Accuracy of CBCT measurements was comparable to the digital caliper measurements.
Al-Ekrish & Ekram,[34]	Investigate the accuracy and reability of linear measurements of edentulous ridges recorded from 16-row MSCT images and CBCT images acquired using a flat panel detctor (FPD) with a large FOV , both independently and in comparison with each other..	CBCT (Iluma®, Imtec Imaging, 3M Health Care, Ardmore, OK, EUA)	Iluma Vision 3D®, Imtec Imaging, 3M Health Care, Ardmore, OK, EUA	The overall mean of the absolute errors was 0.75 mm for MSCT and 0.49 mm for CBCT. The mean of the CBCT absolute errors was smaller than that of the MSCT absolute errors for the overall data, as well as for the site-specific data. CBCT measurements were significantly more accurate than those of MSCT.
		MSCT 16 slices (Light Speed 2002®, GE Medical Systems, Waukesha, WI, EUA)	DentaScan Plus®, GE Medical Systems, Waukesha, WI, EUA	
Cremoni	Evaluate the influence of	CBCT (iCAT®,	Imaging	For the MSCT, dental metallic artefact produced

ni et al .[35]	dental metallic artefacts on implant sites using MSCT and CBCT.	Imaging Sciences International, Hatfield, PA, EUA) MSCT 64 slices (Aquilion®, Toshiba Medical, Tustin, CA, EUA)	Studio®, Anne Solutions, São Paulo, Brazil	an increase of 5% in bone thickness and a reduction of 6% in bone height. CBCT, metallic artefact produced an increase of 6% in bone thickness and a reduction of 0.68% in bone height In both techniques, no significant differences ($p > 0.05$) were detected when comparing measuremnts performed with and without metallic artefacts.
Ganguly et al.[36]	Determine the geometric accuracy of CBCT – based linear measurements of bone height obtained with the Galileos CBCT in the presence of soft tissues .	CBCT (Galileos®, Sirona Dental Systems Inc., Bensheim , Hessen, Germany)	Galaxis®, Sirona Dental Systems Inc., Bensheim, Hessen, Germany	The findings showed no statistically significant difference between the image and physical measurements ($P > 0.05$).
Gribel et al.[37]	Compare the accuracy of craniometric measurements made on lateral cephalograms and on CBCT images.	CBCT (iCAT Next Generation®, Imaging Sciences International, Hatfield, PA, EUA) Radiografia (Orthophos 3C ®, Siemens, Erlagen, Germany)	SimPlant Ortho®, Materialise Dental, Lueven, Bélgica Compass 3D, Belo Horizonte, Brazil ---	No statistically significant difference was noted between CBCT measurements and direct craniometric measurements (mean difference, 0.1 mm). All cephalomtric measurements were significantly different statistically from direct craniometric measurements (mean difference, 5 mm). Some measurements were larger on the lateral cephalogram and some were smaller
Timock et al.[38]	Investigate the accuracy and reliability of buccal alveolar bone height and thickness measurements derived from CBCT images, using comparisons with direct measurements.	CBCT (iCAT®, Imaging Sciences International, Hatfield, PA, EUA)	Dolphin 3D Imaging®, Dolphin Imaging Systems, Chatsworth, CA, EUA	Intrarater reliability was high as were interrater correlations for all measurements ($\geq$ 0.97) except CBCT buccal bone thickness (0.90). CBCT measurements did not differ significantly from direct measurements, and there was no pattern of underestimation or overestimation. The mean absolute differences were 0.30 mm in buccal bone height and 0.13 mm in bucal bone thickness.
Tomasi et al.[39]	Assess the influence of inclination of the object on the reliability and reproducibility of linear measurements of anatomic structures of the mandible on images obtained using CBCT.	CBCT (Promax 3D®, Planmeca Oy, Helsinki, Finland)	Romexis Viewer®, Planmeca Oy, Helsinki, Finland	The mean SD for the radiographic measurements was 0.36 mmfor the horizontally positioned mandible and 0.48 mm for the inclined mandible. The overall absolute mean measurement error was 0.40 mm (SD 0.39 mm). The percentage of errors that exceeded 1 mm was 6.7%.
Al-Ekrish[40]	Investigate the accuracy and reliability of implant site measurements, recorded from low-dose CBCT images.	CBCT (Iluma®, Imtek Imaging, 3M Co., St. Paul, MN, EUA)	IlumaVision 3D®, Imtek Imaging, 3M Co., St. Paul, MN, EUA	The mean absolute errors from the 40, 20 and 7s protocols were 0.50, 0.46 and 0.51 mm, respectively. There was no significant difference in accuracy or reliability between the three protocols.
Benninger et al.[41]	Validate the accuracy of CBCT tooth measurements.	CBCT (iCAT®, Imaging Sciences International, Hatfield, PA, EUA)	iCAT Vision®, Imaging Sciences International, Hatfield, PA, EUA	The difference between the CBCT imaged teeth values and the postextraction digital caliper values were calculated in the vertical, facial to lingual, and mesial to distal dimensions. For all 3 comparisons in each dimension, resulting in no statistically significant difference between the averaged CBCT and the postextraction tooth for each dimension.

Fernandes et al. [42]	Assessed the precision of the dimensional assessment made by CT compared with the same measurement made directly with calipers in the inter-radicular distances between the canine, and first and second premolars, of human mandibles and the thickness of the cortical bone at adjacent sites.	MSCT 2 slices (Spirit®, (Siemens, Erlagen, Germany)	UniViewer.exe. Version 1.0.0.1™	Our findings showed that there was no significant difference in the inter-radicular distance or in the thickness of cortical bone between the sides of the mandible. There was no significant difference in micrometric precision between the dimensional assessment on CT and direct measurement using a caliper.
Patcas et al.[43]	Determine the accuracy of CBCT with different voxel resolutions.	CBCT (KaVo 3D eXam, Brugg, Suiça) CBCT(KaVo Dental AG, Brugg, Suiça)	eXam Vision®, Imaging Sciences International, Hatfield, PA, EUA	Bony measures obtained with CBCT were accurate and differed only slightly from the physical findings. The mean differences, ranging from 0.13 to 10.13 mm, were statistically not significant, but the limits of agreement showed discrepancies in the measurements as large as 2.10 mm, depending on measurement and resolution.
Torres et al.[44]	Evaluate the accuracy of linear measurements on dry mandible specimens using cone CBCT images acquired with different voxel sizes.	CBCT (iCAT®, Imaging Sciences International, Hatfield, PA, EUA)	Xoran®, Imaging Sciences International, Hatfield, PA, EUA	There was no statistical difference between the measurement error of the protocols (P 0.606). The mean value of the difference between the values obtained in the images and the dry mandible was smaller than 1 mm for all the protocols.
Zhang et al.[45]	Evaluate and compare the measurement accuracy of the temporomandibular joint (TMJ) space in the CBCT images scanned with 2 different FOV protocols.	CBCT (Promax 3D®, Planmeca, Helsinki, Finland)	Planmeca Romexis Viewer®, Planmeca, Helsinki, Finland	There were no significant differences among the actual joint spaces and the CBCT measurements performed with the 2 scanning protocols (*P* .305).

Veyre-Gouletet et al.(2008) evaluated the accuracy of linear measurements on the posterior maxilla region provided by CBCT (intensify tube). Fourteen linear measurements were done on three dry maxilla using three radiopaque markers over the alveolar ridge to define a plane. The maxillas were submitted to CBCT scans and the bone height and thickness were accessed with a caliper directly on the bone and on the images using a specific tool from the software. The results showed that there was no significant difference between direct anatomic measurements and CBCT images. The authors concluded that despite the existence of bone density difference between ex vivo and in vivo bone the study indicated that images generated by CBCT could be reliable to establish bone measurements of the posterior maxilla for implant planning.

Suomalainem et al. (2008) aimed to: (i) evaluate the accuracy of linear measurements on CBCT and MSCT images of the posterior region of the mandible (ii) evaluate the accuracy of exams with low-dose X-radiation and (iii) evaluate the reproducibility intra and interexaminer. A human dry mandible was examined in two edentulous areas and a dentade area using CBCT and four channel MSCT. The mandible was examined before and after immersion in isointense sucrose solution, however MSCT low dose was performed only on the immersed mandible. Two examiners measured four linear distances. The mandibles were sectioned into slices with a thickness of 4mm in three regions. These sections were scanned by a microCT and these images were used as gold standard for the measurements. The intraclass correlation index (ICI) obtained for intra e interexaminer results showed no significant differences, either for anatomical or image measurements. The measurement error (ME) showed significant differences between anatomical and image measurements (p = 0.022), mean ME was 4.7% and 8.8% for CBCT and MSCT, respectively, for dry mandible and 2.3% and 6 6% respectively for immersed mandible and 5.4% for the low dose MSCT. The MSCT reduction of radiation dose was less than ¼ of the value of the original conventional dose and did not significantly affect ME. The conclusion was that CBCT was a reliable tool for measuring implant sites compared to four channels MSCT.

Gahleitner et al. (2008) investigated the accuracy of measurements of the diameter of the crown of teeth by CBCT for the preoperative diagnosis before dental transplantation. The sample consisted of 58 patients undergoing CBCT of the jaws for the extraction of impacted teeth. Bucolingual and mesiodistal diameters were measured in all transverse reconstruction image sections of 101 tooth crowns indicated for extraction, but only the highest values were recorded for comparison with direct measurements obtained postoperatively using a caliper. There were no significant differences in measurements in the buccolingual direction between caliper and CBCT measurements. However, in the

mesiodistal direction the caliper measurements were higher than CBCT, so CBCT underestimated the distance in this direction. On average, CBCT measurements were 0.96% higher than the caliper measurements for buccolingual distances and 2.32% lower for mesiodistal distances. The authors concluded that CBCT provides accurate information about the diameter of the crown of impacted teeth in a submillimeter scale although it may slightly underestimate these measurements.

Kamburoglu et al. (2009) studied the accuracy and reproducibility of measurements on CBCT images around specific sites around the mandibular canal. For this six hemimandibles with soft tissue and orthodontic wires marking seven reference points were submitted to CBCT examinations. It was created by software panoramic reconstruction and transversal from the reference points which were used to gather measurements of the same distances obtained by caliper directly of the specimen (of the seven reference points). The intraexaminer concordance for all distances was high (0.86 to 0.97 for CBCT and 0.98 to 0.99 for direct measurements) though the repeatability for CBCT ranged from 0.78 to 2.05 and 0.43 to 1.07 for direct measurements (caliper). The interrater measurements for all distances also showed high concordance. The level of agreement ranged from .84 to .97 for CBCT and 0.78 to 0.97 for direct measurements , however repeatability for measurements on CBCT ranged from 0.76 to 1.99 and 1.22 2.59 for direct measurements . The intraclass correlations of measurements on CBCT and direct measurements ranged from 0.61 to 0.93 for the first examiner and 0.40 to 0.95 for the second examiner.

AL – Ekrish & Ekram in 2011 investigated the accuracy and reliability of linear measurements of edentulous area images of human dry mandibles. The images were generated by MSCT (16 channels) and CBCT. The CBCT images were obtained using a large field of view (FOV). The evaluations were performed independently and comparing the images from both equipments. MSCT axial images were reformatted by Dentascan Plus® software to acquire crosssectional images. CBCT images were processed with IllumaVision 3D® software. The dimensions studied were measured in the images by two observers and compared to direct measurements. The results showed that the overall average absolute error was 0.75 mm for MSCT (16 channels) and 0.49 mm for CBCT. The average absolute error of CBCT was lower than the MSCT for all data as well as for the site-specific data. The score for intra-rater reliability was 0.994 for MSCT and 0.995 for CBCT. The interrater reliability was 0.985 and 0.958 for MSCT and CBCT, respectively. The authors concluded that both CTs were associated with a ME clinically and statistically significant . CBCT measurements were significantly more accurate than the MSCT. Measurements recorded from both image modalities had a high reliability intraexaminers.

Cremonini et al . (2011) evaluated the influence of metal artifacts on the linear measurements taken in cross-sectional images of the alveolar crest using CBCT and MSCT 64 channels. Ten dry human mandibles were scanned in both techniques, with and without dental metal artifacts. Metallic restorations were placed on top of adjacent alveolar crest to the mental foramen region. Linear measurements (thickness and height) for each cross-section were recorded by an examiner using the Imaging Studio® software. All mandibles were analyzed both sides, right and left, on the mental foramen region. For MSCT, metallic artifacts produced a 5% increase in bone thickness and 6% reduction in bone height. On CBCT images, metallic artifacts produced a 6% increase in bone thickness and 0.68 % reduction in bone height. There was no significant differences ($p>0.05$) when compared measurements made with and without metal artifacts for MSCT and CBCT. The presence of metallic artifacts was not able to significantly change the linear measurements obtained with both image modalities, on the other hand their presence made more difficult to locate the alveolar crest .

Ganguly et al. (2011) aimed to determine the geometric accuracy of CBCT Galileos® through linear measurements of bone height in the presence of soft tissues. Six embalmed cadaver heads were scanned after installing radiopaque markers on the buccal and lingual cortical plates. Linear measurements of bone height were obtained using software. Direct measurements were obtained using a caliper on the marked distances and these distances were compared to all measurements obtained on the six jaws bilaterally to determine the accuracy of on CBCT images. The findings showed no significant differences between the images and the direct caliper measurements ($p > 0.05$). The ICIs was used to measure the intra-examiner reliability of repeated measurements and no significant differences between measurements were found for the marked locations. The authors concluded that linear anatomic measurements on CBCT images of the mandible in the presence of soft tissue are sufficiently accurate for clinical use.

Gribel et al (2011) compared the accuracy of craniometric measurements on lateral cephalograms and on CBCT images. Twenty-five dry skull with ten radiopaque markers as landmarks underwent lateral radiographs (ORTHOPHOS 3C ®) (later printed on film) and CBCT (i-CAT ®). Direct craniometric measurements were compared to measurements on CBCT images of MPR and cephalometric measurements on radiographs. There were no significant differences between the direct measurements and CBCT (mean difference 0.1). There were significant differences between all cephalometric measurements on printed film and direct measurements of skulls (mean difference of 5mm). The authors concluded that craniometric measurements from CBCT and reformatted for 3D cephalometric software are extremely accurate and can be used for craniofacial analysis.

Timock et al. (2011) investigated the reliability and accuracy of the measurements of height and thickness of the buccal alveolar bone CT scans on cadaver heads. Twelve embalmed heads were scanned with CBCT (i-CAT ®). The height and thickness of the buccal cortical of CBCT images of 65 teeth were compared to direct measurements after dissection. Intra and interrater ICI were high for all measures (> 0.97) except for the thickness of the buccal bone on CBCT images (0,90). There were no significant differences between the direct measurements and images. For protocol used in this study, CBCT can be used to quantitatively assess the height and thickness of the vestibular bone with high accuracy. Comparing the two sets of measurements of the CT images, the buccal bone height was more accurate and reliable than the measurements of bone thickness.

Tomasi et al. (2011) assessed the influence of inclination of the object on the accuracy and reproducibility of linear measurements of the mandible on CBCT images. Ten linear distances between anatomical points were measured with a caliper on dry jaw. The mandible was then scanned parallel to horizontal plane and also 45°angle. The overall absolute mean measurement error was 0.40mm (SD 0.39mm) and the percentage of errors that exceeded 1mm was of 6.7%. The results showed high reliability of measurements performed on CBCT regardless of the position of the object and the examiner experience.

Al-Ekrish (2012) investigated the accuracy and reproducibility of linear measurements at implant sites, registered on CBCT images with reduced exposure time. Images of five skulls were obtained using three protocols with exposure times: 40, 20 and 7s. The dimensions of edentulous sockets were measures on CBCT images by two observers and compared with direct measurements of bone. The mean absolute error for the exposure time 40, 20 and 7s was 0.50, 0.46 and 0.51 mm, respectvely. Intra-examiner reproducibility was 0.996, 0.995 and 0.998 respectively and inter was 0.993, 0.998 and 0.994. The author concluded that there were no significant differences among the CBCT three exposure times, and that reducing the exposure time did not affect the accuracy and reproducibility of measurements at implant sites on CBCT jmages.

Benninger et al. (2012) aimed to validate the accuracy of dental measurements on CBCT images. Twelve embalmed cadavers were scanned by CBCT in head and neck region. Sixty nine teeth were collected and measured with a caliper. The iCATVision® was used to measure tooth vertical and buccolingual mesiodistal dimension on images. There were no significant differences for each dimension. They concluded that using the iCATVision® measurements on CBCT images it was possible to obtain the actual dimensions of the teeth, benefiting implant surgery.

Fernandes et al. (2012), calculated the inter-radicular distances between the canine, and first and second premolars, of human mandibles and the thickness of the cortical bone at adjacent sites using a two channels MSCT (Spirit®Siemens) imaging, and assessed the precision of the dimensional assessment made by CT compared with the directly measurement with calipers. The images were from 100 human hemimandibles. They evaluated the accuracy of these distance measurements comparing them to direct measurements made with caliper on bone. The results showed no significant differences in micrometric precision between the dimensional assessment on CT and direct measurement using caliper. The authors concluded that MSCT is a reliable tool to measure the inter-radicular distance and mandibular cortical thickness.

Patcas et al. (2012) investigated the accuracy of CBCT with different voxel resolutions. Measurements were made in the buccal bone in the region of the mandibular incisors in eight cadaver heads. The heads were submitted to CBCT using two resolutions voxel (0.125 mm and 0.4 mm). The mucosa around the teeth was removed to allow direct bone measurements. The bone measurements on CBCT in both protocols were accurate and the mean differences, ranging from -0.13 to +0.13 mm, were statistically not significant, but the limits of agreement showed discrepancies in the measurements as large as 2.10 mm, depending on the measurement and resolution. CBCT renders anatomic measures reliably and is an appropriate tool for linear measurements. The 0.125 mm voxel protocol does not depict the thin buccal alveolar bone covering reliably, and there is a risk of overestimating fenestrations and dehiscence. The limits of agreement indicated that 1mm alveolar thickness can be completely lost, even with a high-resolution protocol. Torres et al. (2012) availaram the accuracy of linear measurements on dry mandibles using CBCT (i-CAT) images with different voxel sizes. Eight dry mandibles were scanned using four voxel sizes (0.2MM, 0.25mm, 0.3mm and 0.4mm). Measurements on CBCT images were compared to the directly obtained on the mandible. There was no statistical difference between the measurement error of the protocols (P= 0.606). The mean value of the difference between the values obtained in the images and the dry mandible was smaller than 1mm for all the protocols. In this study the accuracy of horizontal and vertical measurements, using four CBCT voxel sizes, was shown to be comparable with the direct measurements on the dry mandible.

Zhang et al. (2012) evaluated and compared the measurement accuracy of the temporomandibular joint (TMJ) space on CBCT(3D Promax®) images scanned with two different FOV sizes. Forty TMJ in 20 dry human skulls were used. TMJ space impression models were made according to the occlusion. ATMs were scanned with standard (80 X 80 X 80 mm) and extended (150 X 110 X 80 mm) FOV. The images were reformatted and compared with direct measurements

on dry skulls. The authors concluded that there were no significant differences between the measurements obtained on dry mandibles and the two protocols of CBCT images.

DISCUSSION

The accuracy of the measurements of linear distances is critical for surgical placement of implants and other dental procedures performed near important anatomic structures such as the alveolar canal inferior.[37] Several studies have been conducted to determine the accuracy of CBCT but few addresses the helical CT. Different CT scanners are available and provide images to be reformatted in innumerous softwares. Therefore the knowledge of the advantages and disadvantages of these different techniques of obtaining and processing the images for the diagnosis and planning of dental treatment are very important, once that linear measurement are established from these images to plan surgeries and implant placements. This systematic review attempted to clarify and facilitate the acquisition of information available.

Many articles addressed studies on tomographic images, but few reported the accuracy as the study objective. When the articles inclusion criteria were applied to filter the appropriate articles, a total of sixteen studies were selected for this systematic literature review. Recent publications were found, which allowed the inclusion of articles published since 2008. The CBCT have been developed for use in the dental field, in this review fifteen articles evaluated different CBCT machines and concluded that the linear measurements on the images are accurate and reliable in a submillimeter scale since appropriate software was used. In some studies the mesiodistal tooth distances were underestimated compared to direct measurements. In the study by Al-Ekram and Ekrish (2011), measurements of CBCT images were significantly more accurate than the MSCT. In the study by Cremonini et al (2011) the presence of metallic artifacts did not interfered on the image linear measurements despite the literature suggested that these artifacts can cause noise and degraded the image formation. Tomasi et al. (2011) showed that changing the position of the object 45 degrees does not change the accuracy of the linear measurements compare to the initial position measurements, and these results revealed high reliability of measurements performed on CBCT images independently from object position, examiner's experience and high reproducibility in repeated measurements settings. In the study by Al-Ekrish (2012) with diminution of of CBCT exposure did not adversely affect the accuracy of the images, but for the exposure of 7s the authors suggested further studies. According to Patcas et al. (2012) the voxel size can alter the accuracy of CBCT linear measurements and even the protocol with voxel of 0.125 mm may represent bone thickness of 1mm. This limitation would be responsible for the overestimation of areas of bone dehiscence.

Helical CT widely used in the medical field has undergone technological changes in order to obtain data in shorter time and later it was introduced MSCT or multslice CT. In the study by Suomalainen et al . (2008) the reduction of radiation dose of MSCT to less than ¼ of the original value did not significantly affect the measurement accuracies. The radiation dose of this technique is one of the disadvantages reported in the literature and this study showed the possibility of reduction without impairs. Al - Ekram and Ekrish (2011) reported that in a study with 16 channels MSCT and CBCT. CBCT was more accurate, but different softwares were used for image processing and this may have affected the results. In the study of Cremonini et al. (2011) the presence of artifacts has not affected the accuracy of linear measurements , however there was a 6% reduction in bone height for MSCT 64 channels and only 0.68 % for CBCT. Fernandes et al. (2012) found that measures obtained from images of two channels MSCT showed slightly higher values than those found in direct measurements, nevertheless the differences were not significant. As MSCT is a technique most often employed in the medical field few studies have addressed the accuracy of craniometric measurements on images generated by these scanners.

In conclusion a literature search revealed studies that validated the linear measurements between different anatomic points in human skulls or jaws and all validated the accuracy of measurements in 2D images generated by CBCT and reconstructed in softwares for performing such measurements. Few studies evaluated the linear measurement accuracy on Helical CT and MSCT, nonetheless the articles included in this study revealed measurements accuracy on the images obtained by these scanners. There was a lack of standardization among the articles regarding methodology, CT scanners and software for image reformatation which difficult meta-analysis comparison among the results.

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