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ORIGINAL ARTICLE

The influence of the segmentation process on 3D measurements from cone beam computed tomography-derived surface models

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Abstract To compare the accuracy of linear and angular measurements between cephalometric and anatomic landmarks on surface models derived from 3D cone beam computed tomography (CBCT) with two different segmentation protocols was the aim of this study. CBCT scans were made of cadaver heads and 3D surface models were created of the mandible using two different segmentation protocols. A high-resolution laser surface scanner was used to make a 3D model of the macerated mandibles. Twenty linear measurements at 15 anatomic and cephalometric landmarks between the laser surface scan and the 3D models generated from the two segmentation protocols (commercial segmentation (CS) and doctor's segmentation (DS) groups) were measured. The interobserver agreement for all the measurements of the all three techniques was excellent (intraclass correlation coefficient 0.97–1.00). The results are for both groups very accurate, but only for the measurements on the condyle and lingual part of the mandible, the measurements in the CS group is slightly more accurate than the DS group. 3D surface models produced by CBCT are very accurate but slightly inferior to reality when threshold-based methods are used. Differences in the segmentation process resulted in significant clinical differences between the measurements. Care has to be taken when drawing conclusions from measurements and comparisons made from different segmentations, especially at the condylar region and the lingual side of the mandible.

Keywords Linear accuracy · Cone beam computed tomography · Mandible · Three-dimensional · Segmentation

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Introduction

For an increasing number of indications, cone beam computed tomography (CBCT) is currently the three-dimensional (3D) imaging modality of choice in oral and maxillofacial radiology [1, 2]. Subsequently, oral radiologists are equipped with DICOM data sets, which open new possibilities of data transfer, segmentation, planning, simulation, and image fusion in the field of oral and maxillofacial radiology [3]. CBCT images provide useful data sets to generate both two-dimensional (2D) planar projections and 3D surface or volume-rendered images for the use in orthodontic assessment and treatment planning [4, 5].

Rendering is the process performed by a 3D software program where an object is given particular characteristics to make it appear like a real world object with shadows and transparencies. A volumetric rendering program is needed to construct the 3D surface models from CBCT data sets imported from the CBCT scanner. Each rendering program has its own unique algorithm that transform the raw CT data to vector data by constructing a surface of a triangulated mesh covering the selected surface of interest by applying an algorithm [6]. The surface models constructed from voxel-based data require the input of a threshold value specifying what the structure of interest is [6]. The user determines the threshold value of visible and invisible voxels. Herein lies the major inherent problem associated with the segmentation process: The accuracy of segmentation relies on the gray value and the threshold value entered by the operator [6]. CBCT has many applications in the maxillofacial region. It is used for locating impacted teeth, dental development, limits of tooth movement, airway assessment, and diagnostics of the temporomandibular joint [7]. The 3D surface model can be used to indicate landmarks, making measurements, craniofacial morphology and superimposition, as well as preoperative osteotomy and dental implant planning [6–8].

The accuracy of the derived surface model is of extreme importance for diagnostic purposes, treatment planning, and outcome evaluation. The accuracy of the segmented 3D surface model depends on the gray value and the threshold value that are chosen by the operator during the segmentation process [6]. Automatically determined and operator-independent threshold values can be applied to possibly overcome this problem. However, this process is complicated because CBCT imaging suffers from beam inhomogeneity. This results in variation of image quality among different manufactures [9, 10]. In practice, variations of image quality can result in differences during the segmentation process due to differences of the gray levels of the same object imaged by different scanners.

The accuracy of CBCT images has been confirmed with various CBCT scanners [11–16]. However, the accuracy of surface models derived from CBCT seems to vary [12–16]. Recently, the accuracy of CBCT 3D surface and volume reconstructions based on linear cephalometric measurements has been established to be within 1–2 mm [13, 16]. However, according to our knowledge, the measurement accuracy made on 3D surface models derived from different segmentation protocols has not been reported yet. In addition, it is questionable if segmentations produced by clinicians are clinically viable because the segmentation process could be very time consuming and arduous. To overcome the segmentation problems regarding accuracy and time management, companies specialized in 3D imaging technology now offer a commercial segmentation service. However, to justify the additional cost of this service, the perceived benefits of improved accuracy warrants further investigation. Therefore, the aim of this study is to assess the clinical difference of linear and angular measurements made on 3D CBCT-derived surface models from different segmentation protocols. This will be achieved by comparing models segmented by a commercial rendering company and by an experienced clinician to 3D models derived from a laser surface scanner.

Materials and methods

Our study sample consisted of seven fresh cadaver heads supplied by the Department of Anatomy, University, Medical Centre Groningen, the Netherlands. Ethical approval was granted before starting with this project. In the present study, only surface models of the mandible were used for comparison. A high-resolution laser surface scanner was used to create the reference or gold standard 3D model [17].

Cone beam computed tomography imaging and segmentation protocols

The cadaver heads were scanned with the KaVo 3D exam scanner (KaVo Dental GmbH, Bismarckring, Germany) according to the manufacturer's instructions. The head was positioned and fixated in the scanner with the head facing forward and Frankfurt horizontal plane parallel to the floor. The head was scanned with a 0.3-mm voxel size with a 17-cm field of view [18, 19]. The acquired CBCT DICOM data sets were transferred to a laptop computer before performing the segmentations. Two segmentation protocols were followed. (1) The acquired CBCT DICOM files were sent to Materialise Dental, (Leuven, Belgium) for segmentation. The surface models were segmented by experienced 3D technicians and are referred to as the commercial segmentation (CS) group in this study; the aims of this study was not known to the 3D technicians. (2) CBCT images were exported in DICOM multi-file format and imported into SimPlant Ortho Pro® 2.1 (Materialise Dental, Leuven, Belgium) software on an Acer Aspire 7730G laptop (Acer, s'Hertogenbosch, the Netherlands) with a dedicated 512 Mb video card (Nvidia® Geforce ® 9600M-GT, NVIDIA, Santa Clara, California, USA). The 3D surface models of all CBCT images were generated by a clinician (R.S.) with 3 years experience in 3D CBCT imaging and segmentation using the same software. These segmentations are referred to as the doctor's segmentation (DS) group. To avoid any bias, the aims of this study were neither known to the commercial segmentation service nor to the clinician. Simple segmentation has been used in both groups (Fig. 1).

Laser surface scan procedure

Soft tissue was removed from all the cadaver heads by the dissectors of the Department of Anatomy at the University of Groningen. Thereafter, the cadaver heads were macerated following a standard protocol to remove the remaining soft tissue and to produce dry mandibles. The laser surface scan procedure was performed by a 3D scanning and 3D printing company (CNC consult, Den Bosch, The Netherlands). The dry mandibles were scanned individually using the Metris® ModelMarker D 100 with ESP2 laser surface scanner on a

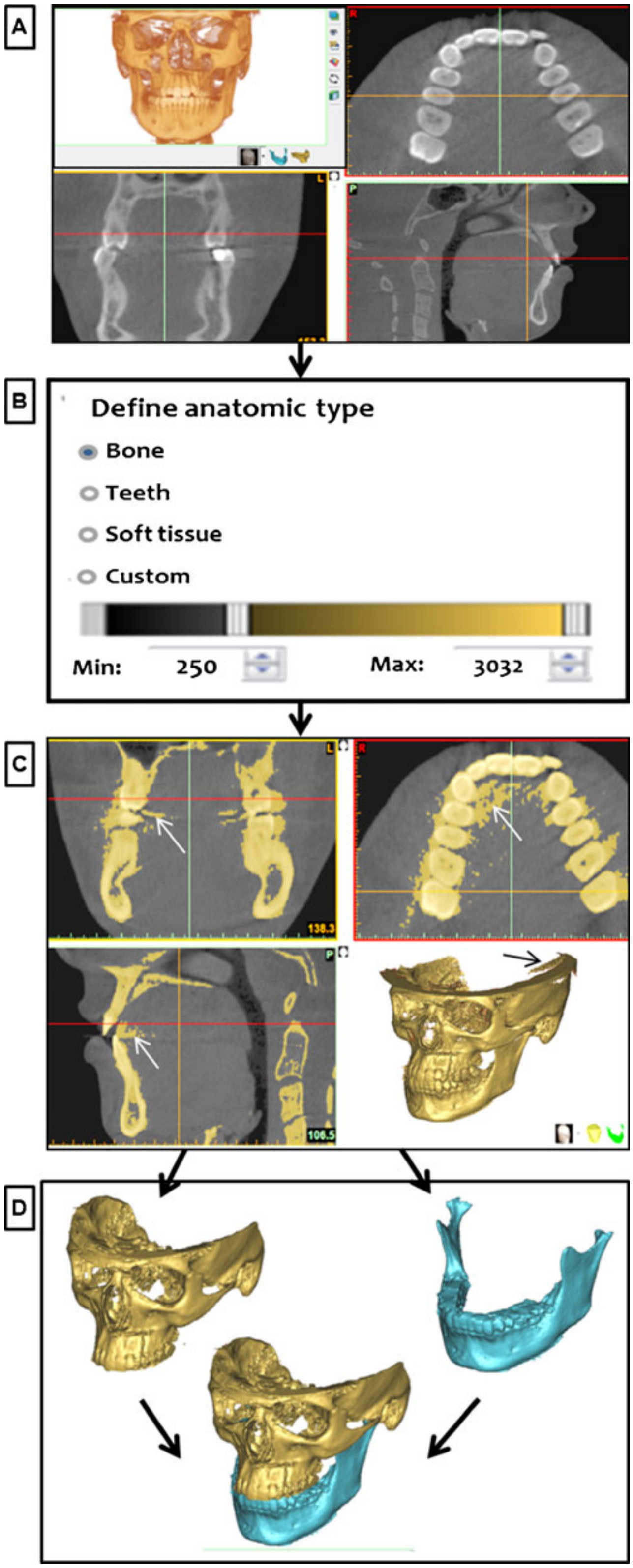

Fig. 1 Schematic illustration of the threshold-based segmentation using SimPlant® Ortho software program. **a** Volume rendering; **b** threshold value selection (operator can manually adjust the threshold); **c** scattering and non-relevant structures removed (indicated by *arrows*); **d** after maxilla is segmented, the process is repeated for mandible. A complete 3D surface model is ready for surgical planning

Metris®2400 M7 Measuring Coordinating Arm (Metris® HQ, Leuven, Belgium). The scanning was performed by an experienced 3D technician. The laser scanner allows obtaining surfaces in the form of a point cloud with an accuracy of 23 μm. The top and the bottom halves of the mandibles were scanned individually and then joined together using Geomagic® Studio 11 (Geomagic® International, NC, America) by the same technician. This process was semiautomatic. Firstly, the two halves were roughly put on each other by a professional 3D technician that is trained to do that. He has to manually indicate a few corresponding anatomical points on both halves. The computer had then put the two halves on each other. The software did the rest of the adjustment automatically to create a best fit. The resulting 3D surface models were extracted as an STL file. The laser surface scanning models were regarded as the reference or "gold standard" and are referred to as the laser surface scanning (LSS) group (Fig. 2).

Measuring procedure

Thirteen linear and seven angular measurements were made between 15 anatomical and cephalometric landmarks (14 bilateral and one unilateral) on the LSS, CS, and DS (Tables 1 and 2 and Fig. 2). These landmarks were chosen to represent the whole surface of the mandible, with the emphasis on landmarks commonly used in cephalometry. These measurements were performed on the LSS, CS, and DS groups separately using the measuring tool of the SimPlant Ortho Pro® 2.1 software. These were repeated five times by one operator (PE) with 1 week apart for all seven mandibles. All the measurements were done on the 3D surface model view of the software (Fig. 3).

Statistical analysis

To measure the intraobserver reliability, the intraclass correlation coefficient (ICC) for absolute agreement based on a two-way random effects analysis of variance was calculated between the five measurement sessions for variable of each 3D surface model technique (e.g., LS, CS, and DS). The results of the ICCs showed that the interobserver agreement for all the measurements of the all three techniques was excellent (ICC, 0.97–1.00). Therefore, the mean of the five repeated measurements was calculated and represented the actual values for each variable of each 3D surface model technique. Mean values and standard deviations were calculated and reported in Table 1.

To determine the clinical accuracy of the CS group and the DS group, the absolute error (AE) was used. Absolute error was defined as the CS or DS value subtracted by the LS value [7]. Mean values, standard deviations, and 95 % confidence intervals of the AE were calculated and reported in Table 2. All statistical analysis was performed with a

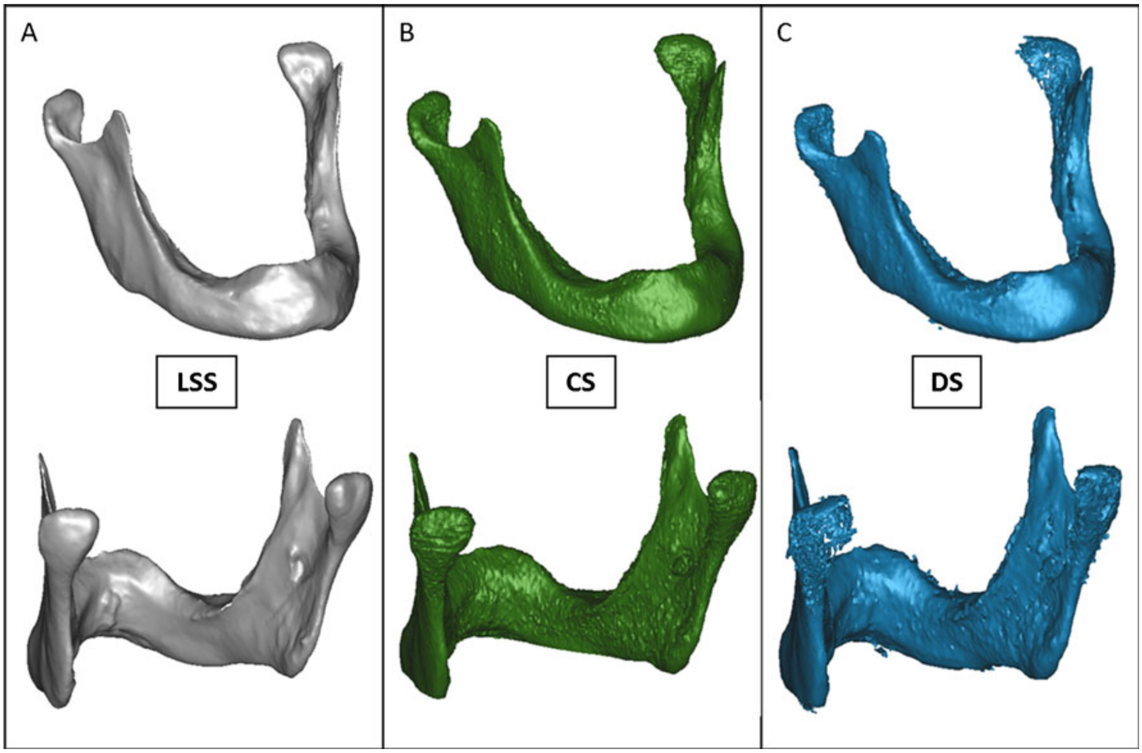

Fig. 2 Isometric and posterior views of the 3D surface models of the **a** laser surface scan (*LSS*); **b** commercial segmentation (*CS*); and **c** doctor's segmentation (*DS*)

standard statistical software package (SPSS version 14, Chicago, IL, USA).

Results

Means, standard deviations, and confidence intervals for the differences of the CS and DS groups from the LSS are summarized in Tables 3 and 4. The linear measurements from both CS and DS groups were generally larger when compared to the LSS model group.

The clinical differences of the measurements were determined with the AE. The results from this study showed that the accuracy was really high for most measurements with around 0.5 mm deviation which is clinically irrelevant, since there is always the observer error in choosing landmark

Table 1 Landmarks used in this study

Landmark and abbreviation		Definition
Me	Menton	Menton is the most inferior midpoint of the chin on the outline of the mandibular symphysis
Co	Condylion	Condylion is the most superior point of each mandibular condyle in the sagittal plane
Go	Gonion	Gonion is the point at each mandibular angle that is defined by dropping a perpendicular from the intersection point of the tangent lines to the posterior margin of the mandibular vertical ramus and inferior margin of the mandibular body or horizontal ramus
AG	Antegonion	Most inferior midpoint of the antegonion notch
CoLat	Condylion laterale	Condylion laterale is the most lateral point of each mandibular condyle in the coronal plane
CoMed	Condylion mediale	Condylion mediale is the most medial point of each mandibular condyle in the coronal plane
Men.for	Mental foramen	The distal part of the mental foramen
Lingula	Lingula mandibulae	The tip of the lingula mandibulae, a sharp spine superior presents in front a prominent ridge at the foramen mandibulae

Table 2 Linear and angular measurements

No	Measurement	Unit		Description
Bilateral measurements				
1 + 2	CoLat-CoMed	mm	Condyle width	Distance between right points CoLat and CoMed
3 + 4	Co-Gn	mm	Ramus length	Distance in millimeter between the point Co and point Gn
5 + 6	Me-Go	mm	Mandibular body length	Distance in millimeter between the point Me and point Go
7 + 8	Co-Me	mm	Total mandibular length	Distance in millimeter between the point Co and point Me
9 + 10	Co-Go-Me	deg	Gonion angle	Angle between a line through the points Co and Go and Me
11 + 12	Co-Me-Go	deg		Angle between a line through the points Co and Me and Go
13 + 14	Go-Co-Me	deg		Angle between a line through the points and Go-Co and Me
Unilateral measurements				
15	Co-Co	mm	Inter-condylar width	Distance between the left and right point Co
16	Go-Go	mm	Mandibular width at Go	Distance between the left and right points Go
17	AG-AG	mm	Mandibular width at AG	Distance between the left and right points Go
18	Men.for–Men.for	mm	Mandibular width at Men.for	Inter-mental foramen width
19	Lingula–lingula	mm	Mandibular width at Mandibular foramina	Intermandibular canal width
20	Co-Me-Co	deg		Angle between a line through the points Co (right)and Me and Co (left)

Linear measurements in millimeters (mm) and degree (deg)

points. In the CS group, the biggest mean AE differences with the LSS models were found at the condylar measurements: condylar width left (95 % confidence interval (CI), 0.91–1.66), right (CI, 0.99–1.90), inter-condylar width (CI, 0.96–3.00), and the measurement between the mandibular width at the mental foramen (CI, 0.11–3.32). In the DS group, the same pattern was seen with the biggest mean AE differences at condylar measurements: condylar width left (CI, 1.26–2.61), right (CI, 0.92–2.65), inter-condylar width (CI, 1.19–3.12), and measurements like mandibular body length (CI, 0.63–2.73) as well as angular measurements: Go angle (CI, 0.85–2.18) and Go-Co-Me (CI, 0.55–2.82).

Discussion

The aims of this study was to assess the linear and angular accuracy measurements done on 3D surface models generated from two segmentation protocols (CS and DS) and to compare these measurements with the LSS that was seen as the gold standard. The results are for both groups very accurate, but only for the measurements on the condyle and lingual part of the mandible, the measurements in the CS group is slightly more accurate than the DS group (Table 4). In the present study, the accuracy was very high for most measurements, around 0.5 mm deviation which

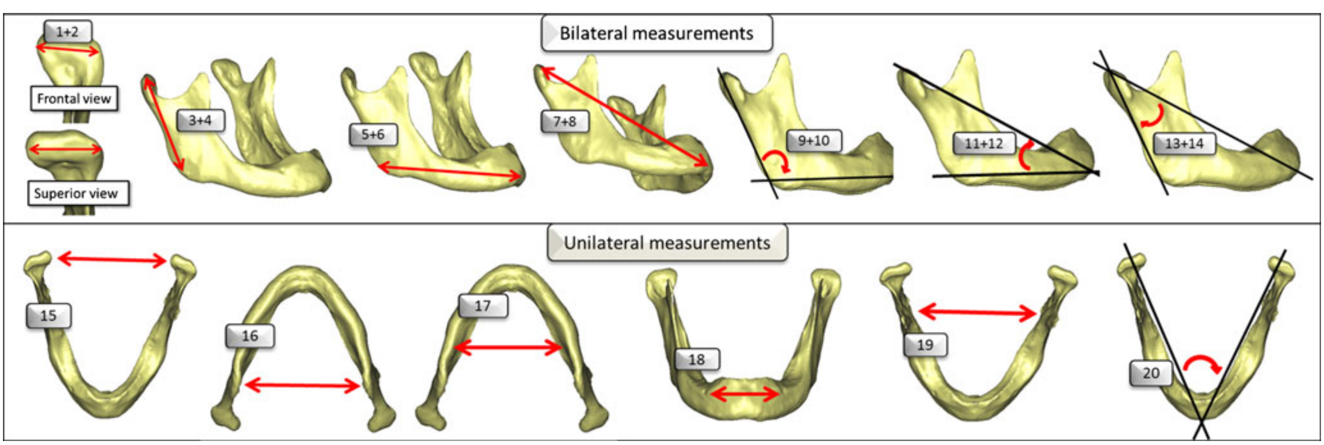

Fig. 3 Measurements used in this study. Bilateral measurements: (*1 + 2*) condylar width, left(L) and right(R); (*3 + 4*) ramus length, L and R; (*5 + 6*) mandibular body length, L and R; (*7 + 8*) total mandibular length, L and R; (*9 + 10*) gonion angle, L and R; (*11 + 12*) Co-Me-Go angle, L and R; (*13 + 14*) Go-Co-Me angle, L and R. Unilateral measurements: (*15*) inter-condylar width; (*16*) mandibular width at gonion; (*17*) mandibular width at antegonion; (*18*) mandibular width at mentalis; (*19*) mandibular width at lingula; (*20*) Co-Me-Co angle

Table 3 Average and standard deviation (SD) of the seven mandibles used for each 3D model technique

	Measurement	Unit	Surface model technique					
			Laser surface (LLS)		Commercial segmentation (CS)		Doctor segmentation (DS)	
			Mean	SD	Mean	SD	Mean	SD
Bilateral measurements								
1	Condyle width (L)	mm	20.26	2.93	21.55	2.74	22.00	3.90
2	Condyle width (R)	mm	20.81	2.40	22.25	2.33	22.59	2.35
3	Ramus length (L)	mm	58.24	3.47	58.21	3.93	58.33	4.16
4	Ramus length (R)	mm	58.74	3.93	58.72	4.21	58.57	4.67
5	Mand body length (L)	mm	84.97	5.95	85.44	5.83	86.50	5.14
6	Mand body length (R)	mm	85.15	5.55	86.04	5.71	86.23	5.68
7	Total Mand length (L)	mm	122.53	7.17	122.91	7.26	122.58	7.48
8	Total Mand length (R)	mm	122.45	6.64	122.89	6.99	122.96	6.72
9	Gonion angle (L)	deg	116.43	3.88	116.45	4.02	114.92	3.93
10	Gonion angle (R)	deg	115.39	3.36	114.84	3.66	114.86	3.83
11	Angle 1 L (Co-Me-Go)	deg	25.21	2.13	25.12	2.38	26.76	4.11
12	Angle 1 R (Co-Me-Go)	deg	25.72	2.38	25.72	2.32	25.63	2.60
13	Angle 2 L (Go-Co-Me)	deg	38.35	2.64	38.43	2.42	40.04	2.62
14	Angle 2 R (Go-Co-Me)	deg	38.89	2.22	39.44	2.73	39.50	2.85
Unilateral measurements								
15	Inter-condylar width	mm	104.65	5.29	105.59	5.72	104.39	6.91
16	Mand width (Go)	mm	95.46	5.46	95.90	6.06	96.47	5.75
17	Mand width (AG)	mm	82.95	2.98	83.12	3.29	82.72	3.38
18	Mand width (Men.for)	mm	46.59	3.51	47.70	4.96	46.64	3.66
19	Mand width (Lingula)	mm	82.33	4.11	82.45	3.88	82.24	4.34
20	Angle 3 (Co-Me-Co)	deg	50.64	2.21	50.95	2.43	50.38	2.96

was seen as clinically relevant. The biggest deviation from the LSS in both the CS and DS groups were found in the measurements from the condylar area and measurements relating to the lingual side of the mandible. Most of these measurements had an AE with a standard deviation of larger than 0.5 mm. This has a clinical implication for instance in the diagnosis of condylar hyperplasia, condylar arthritis, and asymmetry of the ramus of the mandible. This agrees with the results from a previous study performed by our group [20]. There are a few explanations why it is difficult to perform an accurate segmentation of the condylar area. The lower density of the bone in the condylar area compared to the rest of the mandible, a lot of overlapping bony structures, and the difficulty to separate the condyle with the discus articularis during segmentation could explain the inaccuracies of condylar segmentations. The inaccuracies of the lingual area might be a result of the scattering of the beam and artifacts caused when the beam passes through the buccal cortical bone during the acquisition. The image artefacts associated with the CBCT affect the segmentation accuracy which directly influences the landmark identification and the resulting measurements [18]. Specific artifacts at the mandibular border and the posterior margin of the scan volume were also described by Liang et al. [17]. Those parts were mostly located near the periphery of the scan volume.

The soft tissue attenuation, metallic artifacts, patient motion, voxel size, field of view, patient scanning position, and beam inhomogeneity of CBCT scanners are factors that can significantly influence the quality of the CBCT-derived 3D segmented models and ultimately the measurement distance between landmarks [11, 16, 21]. Although number of basis projection images may also influence measurement accuracy of CBCT images, Damstra et al. [21] found that the voxel size did not have a significant influence on the accuracy of linear measurements of 3D models derived from CBCT for orthognathic surgery purposes [22]. Conversely, the effect of the scanner type on 3D images had a significant influence in the image quality and resulting accuracy of the segmented surface models [22–24].

At present, 3D volumetric representation of a structure depends on accurate segmentation. The threshold can be chosen to improve the bone voxel values and suppress the surrounding tissue values to enhance the structure of

Table 4 Clinical differences between the laser surface models and the commercial (CS) and doctor segmentations (DS) as determined by the absolute error (AE)

Measurement		Unit	LLS vs. CS			LLS vs. DS		
			Mean AE	SD	95 % CI AE	Mean AE	SD	95 % CI AE
Unilateral measurements								
1	Condyle width (L)	mm	1.28	0.51	0.91–1.66	1.93	0.91	1.26–2.61
2	Condyle width (R)	mm	1.44	0.61	0.99–1.90	1.79	1.17	0.92–2.65
3	Ramus length (L)	mm	0.62	0.32	0.38–0.86	0.99	0.79	0.41–1.58
4	Ramus length (R)	mm	0.43	0.49	0.07–0.79	0.83	0.73	0.30–1.37
5	Mandibular body length (L)	mm	0.58	0.70	0.06–1.10	1.68	1.42	0.63–2.73
6	Mandibular body length (R)	mm	1.06	0.53	0.67–1.46	1.35	0.83	0.74–1.97
7	Total mandibular length (L)	mm	0.55	0.40	0.26–0.85	1.21	0.81	0.61–1.81
8	Total mandibular length (R)	mm	0.63	0.47	0.28–0.97	0.95	0.73	0.41–1.49
9	Gonion angle (L)	deg	0.99	0.71	0.46–1.51	1.51	0.89	0.85–2.18
10	Gonion angle (R)	deg	0.78	0.80	0.19–1.37	0.68	0.81	0.08–1.28
11	Angle 1 L (Co-Me-Go)	deg	0.36	0.24	0.18–0.53	0.55	0.64	0.08–1.03
12	Angle 1 R (Co-Me-Go)	deg	0.32	0.28	0.12–0.52	0.41	0.27	0.22–0.61
13	Angle 2 L (Go-Co-Me)	deg	0.68	0.63	0.21–1.14	1.68	1.53	0.55–2.82
14	Angle 2 R (Go-Co-Me)	deg	0.73	0.56	0.32–1.15	0.84	0.61	0.39–1.29
Bilateral measurements								
15	Inter-condylar width	mm	1.98	1.37	0.96–3.00	2.15	1.30	1.19–3.12
16	Mandibular width (Go)	mm	0.88	0.53	0.48–1.27	1.01	0.54	0.60–1.41
17	Mandibular width (AG)	mm	0.58	0.42	0.26–0.89	1.09	0.79	0.50–1.68
18	Mandibular width (Men.for)	mm	1.71	2.17	0.11–3.32	1.04	0.73	0.50–1.59
19	Mandibular width (Lingula)	mm	0.53	0.24	0.36–0.71	0.44	0.34	0.19–0.69
20	Angle 3 (Co-Me-Co)	deg	0.95	0.49	0.59–1.31	1.02	0.91	0.35–1.61

The laser surface models (LS) were used as the reference for comparison

SD standard deviation, *95 % CI AE* 95 % confidence interval of the AE

interest. Our results suggest that probably one of the most significant factors determining the clinical difference of the measurements on the surface models is likely to be the differences between the threshold-dependant methods. Standard preset thresholds for bone, soft tissue, and teeth are often specified and suggested by the software. However, the threshold should still be adjusted by the operator to enhance the quality of a certain region of interest. This process is dependent on the software algorithm, the spatial and contrast resolution of the scan, the thickness and degree of calcification or cortication of the bony structure, and most importantly, the technical skill of the operator [13]. This is why the segmentation process is a very subjective method. In this present study, a simple segmentation method was used. In the DS group, the threshold value was chosen by the clinician according to the visual image that the operator got of the region of interest. In the CS group, the commercial company also used the simple segmentation method but with a much more sophisticated way of determining the threshold value. They used profile lines: these will show a histogram of the pixels that these lines cross. They draw different profile lines in different regions and then calculate a certain threshold of segmentation. This might be one of the explanations for the difference in the quality between the 3D segmented models form the CS and DS groups. In order to overcome this problem, a threshold value automatically determined and observer-independent values can be used. Clinically, the threshold value of the mandible is less than the value of the maxilla [9, 10]. Cortical bone in the mandible is thick enough to keep the attenuation profile inform across the entire bone surface except for the condylar region. In the maxilla, the variations of cortical bone thickness especially in the palate and tuberosity regions create significant bone dehiscence and fenestrations artefacts in the 3D model [6]. It is therefore impossible to choose a single threshold value for bone tissue in single jaw. Due to the differences in bone density of the jaws itself, a single threshold will most likely result in inaccuracies of the resulting segmentation.

In this present study, a laser surface scan was made of the dry mandible. This was regarded as the gold standard for comparison. Laser scanning is a commonly used technique in the engineering industry for acquiring 3D data from objects [25]. It is a valid and reliable technique that is used to detect minute and microscopic defects [21]. It is increasingly being used in medicine, forensic science, physical anthropology, and conservators to document, reconstruct, and analyze objects and human remains, including craniofacial features [18, 25]. Laser surface scanning is reliable and accurate for producing mandibular surface models [17]. The present study did not include the maxilla. This is due to the fact that laser surface scanning of the maxilla is challenging and unreliable. The extremely thin lateral wall of the maxillary sinus and the walls of the orbit allows for the laser to pass through it without being detected [17]. Laser surface scanning of the maxilla is further complicated by the extremely complex geometry of the maxilla.

In this present study, 95 % confidence interval (CI) was used instead of the P values to determine clinical differences. In most research studies, where comparisons are made between groups, some form of statistical analysis is performed and a test or a number of tests of significance are reported with corresponding P values. However, P values do not always give an indication regarding the clinical importance of the observed results [26]. A more appropriate presentation of the trial results would focus on the size of the difference between the treatment groups and its range, i.e., the 95 % CI [27]. The CIs provide a range of values within which the true difference of the study groups is believed to exist, thus giving the reader the opportunity to interpret the results in relation to clinical practice [26].

Inherent clinical inaccuracies of both landmark identification and measurement associated with the 3D images are a major source of measurement error [13, 28]. Therefore, efforts should be made to minimize the effect of errors in landmark identification [15, 28]. In previous studies, fiducial reference markers were placed to establish a consensus landmark location. However, this was not possible in our study as the soft tissue was still intact when the CBCT scans were made. In the present study, all measurements were performed by one observer. The measurements were made only once. If systematic errors were made by the observer in identification of the landmarks, it would have been the same for all three types of surface models, and therefore have no influence on reproducibility of the measurements. This was confirmed by the ICCs of repeated measurements. Hence it is justified to have one observer for this type of study.

The present study is unique because fresh cadaver heads were used to make the CBCT scan. After maceration of the skulls, laser surface scanning was applied to produce true surface models of the mandibles. With this method, all data from the same head could be compared and no artificial media were needed to mimic soft tissues. Moreover, if only the mandible is scanned, the missing cervical vertebra and skull base could influence the results [17]. For this reason, Liang et al. suggested that full cadaver skull including both lower and upper jaws with soft tissue and cervical vertebra should be used [17]. In the present study, a full fresh cadaver head with cervical vertebrae were used for the CBCT scans which overcame problems associated with methods previously described using dry skulls.

The results of the present study confirm that measurements derived from landmarks on the condyle and lingual region of the mandible are less accurate than reality. However, the measurements of 3D models of the CS group were more accurate at the condylar region when compared to the DS group. Therefore, it might be preferable to send the scan to a professional company for the segmentation when highly accurate results at these regions are required.

Conclusion

3D surface models produced by CBCT are very accurate but slightly inferior to reality when threshold-based methods are used. Therefore, care has to be taken when drawing conclusions from measurements and comparisons made from different segmentations. In the present study, the segmentations made by the doctors were in general very accurate. However, in some cases, it might be preferable to have a more advanced segmentation technique especially at the condylar region and the lingual side of the mandible.

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