RESEARCH

Comparison of precision and accuracy of linear measurements performed by two different imaging software programs and obtained from 3D-CBCT images for Le Fort I osteotomy

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Objective: The purpose of this study was to compare the precision and accuracy of linear measurements for Le Fort I osteotomy performed by two different imaging software programs and obtained from three-dimensional cone beam CT (3D-CBCT) images.

Methods: The study population consisted of 11 dried skulls submitted to CBCT, which generated 3D images. Linear measurements were based on craniometric anatomical landmarks pre-defined by the authors as specifically used for Le Fort I osteotomy and were identified by two radiologists twice each, independently, using Vitrea 3.8.1 (Vital Images Inc., Plymouth, MN) and open-source digital imaging communication in medicine viewer OsiriX 1.2 64-bit (Pixmeo, Geneva, Switzerland). Subsequently, a third examiner made physical measurements using a digital caliper (167 series; Mitutoyo Sul Americana Ltd, Suzano, SP, Brazil).

Results: The results demonstrated a statistically significant difference between OsiriX and the gold standard, especially in the pterygoid process (TPtg L = 0.019, LLpPtg R = 0.016 and LLpPtg L = 0.012). Vitrea showed no statistical difference in comparison with the gold standard, and showed a high level of accuracy in all the measurements performed. The major difference found was 0.42 mm (LLpPtg R). Interexaminer analysis ranged from 0.90 to 0.97 using Vitrea and from 0.8 to 0.97 using OsiriX. Intraexaminer correlation coefficient ranged from 0.90 to 0.98 and from 0.84 to 0.98 for Examiners 1 and 2, respectively, using Vitrea and from 0.93 to 0.99 for Examiner 1 and from 0.64 to 0.96 for Examiner 2 using OsiriX.

Conclusion: Vitrea may be considered as precise and accurate, insofar as it was able to perform all the 3D linear measurements. On the other hand, linear measurements performed using OsiriX were not successful in producing accurate linear measurements for Le Fort I osteotomy.

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Introduction

The surgical correction of dentofacial deformities is determined by several factors, such as anatomical knowledge, surgical techniques and the surgeon's experience.

The success of this procedure depends on precise and accurate facial analysis and on image exams that represent an essential determinant in correcting facial deformities, in securing stable results and in reducing the surgical complications that may pose a risk to patients.¹⁻³

Advances in craniofacial imaging and image acquisition techniques, such as the introduction of cone beam CT (CBCT), have improved the understanding of

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anatomical structures and possible anatomical differences. Improved visualization quality could prevent surgery-related complications such as haemorrhage,³ permanent neural disorders and unplanned fractures.⁴

The three-dimensional (3D) software programs currently available have been developed specifically to assist diagnosis and treatment planning and to predict outcomes related to orthognathic surgery.^{1,2,5,6} However, there are many commercial and open-source software programs available on the market with different linear measurement methods. Some of these software applications determine linear measurements based on pre-determined points that are marked using multiplanar reconstruction (true 3D measurements—Vitre software; Vital Images Inc., Plymouth, MN), as opposed to other applications that perform measurements on the 3D reconstructed images (OsiriX software; Pixmeo, Geneva, Switzerland). No publications were found in the literature review regarding rigorous experimental controls to validate 3D CBCT for Le Fort I osteotomy or the efficiency of OsiriX open-source digital imaging communication in medicine (DICOM) viewer software to conduct this validation.

The aim of this study was to compare the precision and accuracy of linear measurements for Le Fort I osteotomy performed by two different imaging software programs and obtained from 3D CBCT images.

Materials and methods

The study population consisted of 11 intact human skulls (8 male and 3 female), age 19–56, provided by the Department of Anatomy of the Federal University of São Paulo, São Paulo, Brazil, following approval by the Institutional Review Committee/Human Specimens Committee (0105.0.017.000-11). There was no ethnic or gender preference for choosing the sample, and no history of bone disease identified in the medical records.

Before scanning the skulls, the mandibles were fixed to the skulls in central occlusion using a tape. The skulls were placed in a bulk bag with water for beam attenuation and to mimic the soft tissues following the procedures previously described by Lopes *et al*,⁷ Moreira *et al*⁸ and Albuquerque *et al*.⁹

The skulls were then placed in the CBCT to keep them in a position similar to that of a clinical situation, *i.e.* they were submitted to CBCT in an i-CAT Cone Beam 3D Dental Imaging System (Imaging Sciences International, Hatfield, PA) at 0.25-mm voxel size for 40 s to acquire raw data. The field of view was a 20 cm height and 16 cm diameter cylinder. The greyscale range of the acquired images was 14 bits. After the original image was acquired, these data were recorded and stored in DICOM format to prevent data loss.

Multiplanar (MPR; axial, coronal and sagittal) and 3D CBCT-reconstructed images using bone protocol were obtained simultaneously and generated in the Vitrea v. 3.8.1 software installed in a Dell 650 Precision (Dell

Computer Corp., Round Rock, TX) independent workstation running the Windows XP (Microsoft, Redmond, WA) operating system. The same images were also obtained in the OsiriX MD v. 1.2 64-bit software; <http://www.osirix-viewer.com/>) installed in an iMac OS X v. 10.6.8 (Apple Inc., Cupertino, CA) independent workstation.

Linear measurements of 3D co-ordinates used for this study were obtained using the anatomical structures described in Table 1. Most of the bone structures were selected specifically for the study instead of using traditional craniometrical points, insofar as analysis of these structures is highly relevant for planning Le Fort I osteotomy (Table 1).^{10–12}

The examiners analysed all volumes scanned using axial and MPR images and pointed to the first landmark of the anatomical structure using an arrow or a circle for both tested software programs. This first landmark was performed on the MPR and automatically transferred to the 3D reconstructed image. The examiners verified and confirmed the exact location of the marked pre-defined structure point using multiplanar guide for axial, coronal and sagittal images and rotation, translation, zoom and transparency software tools for 3D reconstructed images. These available tools allow examiners to analyse the 3D reconstructed images on different spatial planes to confirm the chosen anatomical landmark. This point was considered as the initial mark for linear measurements. The volume was then analysed again, and the second point was determined following the same steps described above.

Differences between both software programs were found in performing the linear measurement calculations. In the case of Vitrea, the software automatically calculated the smallest distance between the two anatomical landmarks displayed in the 3D reconstructed image. This image represents the initial and final points of the anatomical structure under study. The landmarks were then marked on the MPR images. These measurements kept the same anatomical position, even when the 3D reconstructed images were rotated and translated (Figure 1). In the case of OsiriX, the same procedure as that performed with the Vitrea software was used to analyse the MPR images (Figure 2). However, in the case of the OsiriX software, the examiners had to trace the line between the anatomical landmarks directly on the 3D reconstructed images, to join the points previously marked in the MPR images and then to obtain the measurements. After the rotation and translation of the 3D images, the measurements moved from their original position on the 3D reconstructed images according to the spatial plane on which the line was drawn (Figure 3). This methodology makes linear measurements two-dimensional. This action was necessary because the professional was not sure about the spatial plane chosen to represent the smallest distance between the craniometrical anatomical previously determined landmarks.

Table 1 Description of craniometrical anatomical structures and respective linear measurements

Anatomical structures	Description
Length of maxilla (ANS–PNS)	Distance between anterior (ANS) and posterior nasal spine (PNS) determining the total length of the maxilla
Length of lateral nasal wall ^a (LNW)	Distance between pyriform aperture (15 mm above the anterior nasal spine) up to the anterior portion of descending palatine artery canal determining the length of the lateral nasal wall
Length of the pterygoid process ^a (LPtg)	Distance representing the length of the bone fusion of the pterygoid process of sphenoid bone to the tuberosity of the maxilla (lateral view)
Thickness of the junction between the pterygoid process and the tuberosity of the maxillary ^a (TPtg)	Distance between lateral and medial point of the bone fusion of the pterygoid process to the tuberosity of the maxilla representing the length of the bone fusion (axial view)
Length of lateral plate of the pterygoid process ^a (LLpPtg)	Distance between a point in the pterygoid fossa (that was the shortest distance to the descending palatine artery canal) and the distal portion of the lateral pterygoid plate representing the length of lateral plate of the pterygoid process
Length of medial plate of pterygoid process ^a (LMpPtg)	Distance between a point in the pterygoid fossa (that was the shortest distance to the descending palatine artery canal) and the distal portion of the medial pterygoid plate representing the length of medial plate of the pterygoid process

^aMeasurements made on right (R) and left (L) sides of the anatomical structure.

The measurements ($n = 11$) were performed electronically by two oral and maxillofacial radiologists, with extensive experience in interpreting CT and knowledge of the software tools. The radiologists were previously calibrated (twice each) independently, with a 7-day time interval between the repeated measurements to ensure intraexaminer reliability.

To obtain the physical data, a third examiner performed the same set of landmarks directly on the dry skull with no knowledge of imaging measurements. Linear dry skull measurements were obtained with a digital caliper (167 series; Mitutoyo Sul Americana Ltd, Suzano, SP, Brazil), this being the same device used by Moreira *et al*⁸ and Lopes *et al*,⁷ with 0.3 mm in an active point.

Data analysis consisted of comparing dry skull measurements (gold standard) with 3D CBCT linear measurements obtained by Vitrea and OsiriX software. The two initial observations of the examiners were

considered as Sample 1 and the two subsequent observations as Sample 2. The Kruskal–Wallis test was used to compare the sample averages of both software programs, and to compare the programs with each other and then with the gold standard. The Mann–Whitney *U*-test was used to compare the Vitrea and OsiriX software to the gold standard. A *p*-value of ≤ 0.05 was considered as indicative of statistical significance.

Results

The results of the linear measurements are shown in Tables 2–5. Table 2 shows the mean value in millimetres using CBCT for both software programs (OsiriX and Vitrea) as well as the physical measurements. According to our findings, Vitrea software presents results closer to the gold standard for all measurements performed than the results obtained with OsiriX, insofar as the major

Figure 1 Three-dimensional (3D) measurement of the length of the pterygoid process (LPtg) R using Vitrea software (Vital Images Inc., Plymouth, MN). The arrows represent the anatomical points chosen using multiplanar reconstruction. (a) Lateral view and (b) oblique view. Note that after rotation, the LPtg R 3D measurement remains over the 3D imaging, depicting a true 3D measurement

Figure 2 Multiplanar reconstruction view, using OsiriX software (Pixmeo, Geneva, Switzerland), showing the same anatomical landmark seen in Figure 1. (a) Sagittal, (b) axial and (c) coronal views

differences found were 0.42 mm (LLpPtg R on Sample 2 using Vitrea) and 2.54 mm (LLpPtg L for Sample 2 using OsiriX).

The interexaminer analysis correlation coefficient ranged from 0.90 to 0.97 using Vitrea software and from 0.8 to 0.97 using OsiriX software, indicating a moderate to almost perfect agreement between examiners (Table 3).

The intraexaminer analysis correlation coefficient ranged from 0.90 to 0.98 and from 0.84 to 0.98 for Examiners 1 and 2, respectively, using Vitrea software indicating almost perfect agreement. Using OsiriX software, the intraclass correlation coefficient ranged from 0.93 to 0.99 for Examiner 1 and from 0.64 to 0.96 for Examiner 2 indicating a moderate to almost perfect agreement (Table 4).

The statistical analysis using the Kruskal–Wallis test showed differences between Vitrea and OsiriX sample averages and the gold standard, especially for measurements performed using the pterygoid process (TPtg R = 0.001, TPtg L = 0.007, LLpPtg R = 0.003 and LLpPtg L = 0.007) (Table 5).

The Mann–Whitney *U*-test was performed to confirm the differences found.

The comparison between Vitrea and gold standard showed no statistical difference in any of the measurements performed, even after analysis using the pterygoid process (LLPtg R = 0.541), which represents the major differences found (Table 6). All the 3D linear measurements performed by Vitrea software showed no significantly different results from those obtained with the average gold standard.

Comparing OsiriX with the gold standard, there were significant differences, especially in the analyses involving the pterygoid process (TPtg R = 0.05, TPtg L = 0.019, LLPtg R = 0.016 and LLPtg L = 0.012). All the linear measurements performed on OsiriX showed lower mean results than those obtained with the gold standard (Table 7).

Discussion

The introduction of 3D tomographic images for orthognathic planning and surgical simulation, together with the rapidly emerging availability of this technology, has broadened the use and application of 3D imaging.^{13–17}

Figure 3 Three-dimensional (3D) measurement of the length of the pterygoid process (LPtg) R using OsiriX software (Pixmeo, Geneva, Switzerland). The point represents the same anatomical landmark shown in Figure 2 in (a) lateral and (b) oblique 3D views. Note that after rotation of the 3D images, the LPtg R measurement moved from its original position over these images, representing a two-dimensional measurement

Table 2 Mean value in millimeters for craniometrical measurements

Sample		Mean value		
		OsiriX	Vitrea	Gold standard
Sample 1	ANS-PNS	50.92	52.18	52.23
	LNW R	42.44	43.30	43.40
	LNW L	41.51	42.76	42.95
	LPtg R	8.93	10.58	10.75
	LPtg L	8.95	10.29	10.01
	TPtg R	8.76	10.50	10.56
	TPtg L	8.61	10.37	10.42
	LLpPtg R	13.92	15.48	15.46
	LLpPtg L	14.73	16.20	16.39
	LMpPtg R	6.48	7.65	7.50
	LMpPtg L	7.53	8.30	8.38
Sample 2	ANS-PNS	51.20	51.85	52.23
	LNW R	42.59	43.35	43.40
	LNW L	41.95	42.92	42.95
	LPtg R	9.06	10.72	10.75
	LPtg L	8.59	9.94	10.01
	TPtg R	8.87	10.62	10.56
	TPtg L	8.46	10.40	10.42
	LLpPtg R	13.05	15.88	15.46
	LLpPtg L	13.85	16.40	16.39
	LMpPtg R	6.60	7.65	7.50
	LMpPtg L	7.65	8.39	8.38

ANS-PNS, distance between the anterior and the posterior nasal spine; LLpPtg L, length of the lateral plate of the pterygoid process on the left-hand side; LLpPtg R, length of the lateral plate of the pterygoid process on the right-hand side; LMpPtg L, length of the medial plate of the pterygoid process on the left-hand side; LMpPtg R, length of the medial plate of the pterygoid process on the right-hand side; LNW L, length of the nasal wall on the left-hand side; LNW R, length of the nasal wall on the right-hand side; LPtg L, length of the pterygoid process on the left-hand side; LPtg R, length of the pterygoid process on the right-hand side; TPtg L, thickness of the junction between the pterygoid process and the tuberosity of the maxillary on the left-hand side; TPtg R, thickness of the junction between the pterygoid process and the tuberosity of the maxillary on the right-hand side.

Sample 1, the two initial observations of the examiners; Sample 2, two subsequent observations.

OsiriX 1.2 64-bit is manufactured by Pixmeo, Geneva, Switzerland; Vitrea 3.8.1 is manufactured by Vital Images Inc., Plymouth, MN.

Table 3 Interexaminer analysis for Vitrea and OsiriX software

Measurement	Interexaminer Vitrea		Interexaminer OsiriX	
	ICC (95% CI)	p	ICC (95% CI)	p
ANS-PNS	0.90 (0.69–0.97)	<0.0001	0.96 (0.88–0.99)	<0.0001
LNW R	0.93 (0.77–0.98)	<0.0001	0.92 (0.73–0.97)	<0.0001
LNW L	0.94 (0.816–0.98)	<0.0001	0.93 (0.76–0.98)	<0.0001
LPtg R	0.95 (0.85–0.98)	<0.0001	0.97 (0.89–0.99)	<0.0001
LPtg L	0.92 (0.75–0.98)	<0.0001	0.85 (0.45–0.96)	0.002
TPtg R	0.96 (0.86–0.98)	<0.0001	0.95 (0.83–0.98)	<0.0001
TPtg L	0.95 (0.84–0.98)	<0.0001	0.95 (0.83–0.98)	<0.0001
LLpPtg R	0.94 (0.80–0.98)	<0.0001	0.95 (0.83–0.98)	<0.0001
LLpPtg L	0.95 (0.82–0.98)	<0.0001	0.80 (0.27–0.94)	0.008
LMpPtg R	0.97 (0.90–0.99)	<0.0001	0.91 (0.72–0.97)	<0.0001
LMpPtg L	0.95 (0.85–0.98)	<0.0001	0.97 (0.92–0.99)	<0.0001

ANS-PNS, distance between the anterior and the posterior nasal spine; CI, confidence intervals; ICC, intraclass correlation coefficient; LLpPtg L, length of the lateral plate of the pterygoid process on the left-hand side; LLpPtg R, length of the lateral plate of the pterygoid process on the right-hand side; LMpPtg L, length of the medial plate of the pterygoid process on the left-hand side; LMpPtg R, length of the medial plate of the pterygoid process on the right-hand side; LNW L, length of the nasal wall on the left-hand side; LNW R, length of the nasal wall on the right-hand side; LPtg L, length of the pterygoid process on the left-hand side; LPtg R, length of the pterygoid process on the right-hand side; TPtg L, thickness of the junction between the pterygoid process and the tuberosity of the maxillary on the left-hand side; TPtg R, thickness of the junction between the pterygoid process and the tuberosity of the maxillary on the right-hand side. OsiriX 1.2 64-bit is manufactured by Pixmeo, Geneva, Switzerland; Vitrea 3.8.1 is manufactured by Vital Images Inc., Plymouth, MN.

A 3D analysis is accurate and is now considered as an essential tool for precise assessment of craniofacial morphology.^{18,19} Several 3D techniques have been developed to compensate for the drawbacks of 2D measurements.^{20,21} Criteria for 3D analyses are essential not only to ensure the accuracy of treatment planning but also to evaluate anatomical structures and plan ahead for possible alterations which may lead to intra- and postoperative complications.^{4,5,22,23}

Table 4 Intraexaminer analysis for Vitrea and OsiriX software

Measurement	Intraexaminer 1 Vitrea		Intraexaminer 2 Vitrea		Intraexaminer 1 OsiriX		Intraexaminer 2 OsiriX	
	ICC (95% CI)	p	ICC (95% CI)	p	ICC (95% CI)	p	ICC (95% CI)	p
ANS-PNS	0.97 (0.90–0.99)	<0.0001	0.94 (0.80–0.98)	<0.0001	0.99 (0.97–0.99)	<0.0001	0.92 (0.72–0.98)	0.0002
LNW R	0.96 (0.87–0.99)	<0.0001	0.84 (0.52–0.95)	0.0003	0.93 (0.77–0.98)	<0.0001	0.87 (0.52–0.96)	0.0016
LNW L	0.96 (0.88–0.99)	<0.0001	0.89 (0.65–0.97)	<0.0001	0.94 (0.80–0.98)	<0.0001	0.82 (0.33–0.95)	0.005
LPtg R	0.96 (0.88–0.99)	<0.0001	0.98 (0.80–0.98)	<0.0001	0.96 (0.86–0.98)	<0.0001	0.96 (0.87–0.99)	<0.0001
LPtg L	0.95 (0.83–0.98)	<0.0001	0.89 (0.66–0.97)	<0.0001	0.98 (0.93–0.99)	<0.0001	0.64 (−0.30 to 0.90)	0.06
TPtg R	0.90 (0.69–0.97)	<0.0001	0.94 (0.81–0.98)	<0.0001	0.95 (0.83–0.98)	<0.0001	0.92 (0.73–0.98)	<0.0001
TPtg L	0.94 (0.79–0.98)	<0.0001	0.94 (0.81–0.98)	<0.0001	0.96 (0.86–0.98)	<0.0001	0.84 (0.43–0.95)	0.003
LLpPtg R	0.96 (0.86–0.98)	<0.0001	0.96 (0.87–0.99)	<0.0001	0.97 (0.91–0.99)	<0.0001	0.74 (0.03–0.93)	0.02
LLpPtg L	0.91 (0.72–0.97)	<0.0001	0.94 (0.79–0.98)	<0.0001	0.98 (0.95–0.99)	<0.0001	0.80 (0.27–0.94)	0.008
LMpPtg R	0.98 (0.93–0.99)	<0.0001	0.97 (0.90–0.99)	<0.0001	0.96 (0.86–0.98)	<0.0001	0.65 (−0.27 to 0.90)	0.52
LMpPtg L	0.98 (0.94–0.99)	<0.0001	0.95 (0.83–0.98)	<0.0001	0.93 (0.77–0.98)	<0.0001	0.94 (0.78–0.98)	<0.0001

ANS-PNS, distance between the anterior and the posterior nasal spine; CI, confidence intervals; ICC, intraclass correlation coefficient; LLpPtg L, length of the lateral plate of the pterygoid process on the left-hand side; LLpPtg R, length of the lateral plate of the pterygoid process on the right-hand side; LMpPtg L, length of the medial plate of the pterygoid process on the left-hand side; LMpPtg R, length of the medial plate of the pterygoid process on the right-hand side; LNW L, length of the nasal wall on the left-hand side; LNW R, length of the nasal wall on the right-hand side; LPtg L, length of the pterygoid process on the left-hand side; LPtg R, length of the pterygoid process on the right-hand side; TPtg L, thickness of the junction between the pterygoid process and the tuberosity of the maxillary on the left-hand side; TPtg R, thickness of the junction between the pterygoid process and the tuberosity of the maxillary on the right-hand side.

OsiriX 1.2 64-bit is manufactured by Pixmeo, Geneva, Switzerland; Vitrea 3.8.1 is manufactured by Vital Images Inc., Plymouth, MN.

Table 5 Kruskal–Wallis test showing comparison between sample mean values and gold standard

Sample	Data analysis	ANS-PNS	LNW R	LNW L	LPtg R	LPtg L	TPtg R	TPtg L	LLpPtg R	LLpPtg L	LMpPtg R	LMpPtg L
Sample 1	χ^2	2.421	2.237	2.628	4.183	3.234	13.598	9.738	5.916	4.173	2.597	1.106
	Degrees of freedom	2	2	2	2	2	2	2	2	2	2	2
	<i>p</i> -value	0.298	0.327	0.269	0.123	0.198	0.001	0.008	0.052	0.124	0.273	0.575
Sample 2	χ^2	1.245	2.109	1.267	3.939	3.486	13.929	9.944	11.891	9.834	0.782	0.891
	Degrees of freedom	2	2	2	2	2	2	2	2	2	2	2
	<i>p</i> -value	0.537	0.348	0.531	0.140	0.175	0.001	0.007	0.003	0.007	0.676	0.640

ANS, anterior nasal spine; L, left; LNW, length of the lateral nasal wall; LLp, length of the lateral plate; LPtg, length of the pterygoid process; PNS, posterior nasal spine; R, right; TPtg, thickness of the junction between the pterygoid process and the tuberosity of the maxillary.

Sample 1, the two initial observations of the examiners; Sample 2, two subsequent observations.

Table 6 Comparison between mean value for Vitrea and gold standard

Sample	Data analysis	ANS-PNS	LNW R	LNW L	LPtg R	LPtg L	TPtg R	TPtg L	LLpPtg R	LLpPtg L	LMpPtg R	LMpPtg L
Sample 1	Mann–Whitney <i>U</i>	120.0	117.0	113.5	114.0	112.0	120.0	116.0	120.0	116.5	117.0	116.0
	<i>Z</i>	−0.038	−0.153	−0.286	−0.267	−0.344	−0.038	−0.191	−0.038	−0.172	−0.153	−0.191
	<i>p</i> -value	0.970	0.879	0.775	0.789	0.731	0.970	0.848	0.970	0.864	0.879	0.849
Sample 2	Mann–Whitney <i>U</i>	114.0	120.0	121.0	120.0	120.0	116.0	120.0	105.0	116.0	114.0	119.0
	<i>Z</i>	−0.267	−0.038	0.000	−0.038	−0.038	−0.191	−0.038	−0.611	−0.191	−0.267	−0.076
	<i>p</i> -value	0.789	0.970	1.000	0.970	0.970	0.849	0.970	0.541	0.849	0.789	0.939

ANS, anterior nasal spine; L, left; LNW, length of the lateral nasal wall; LLp, length of the lateral plate; LPtg, length of the pterygoid process; PNS, posterior nasal spine; R, right; TPtg, thickness of the junction between the pterygoid process and the tuberosity of the maxillary.

Sample 1, the two initial observations of the examiners; Sample 2, two subsequent observations.

Vitrea 3.8.1 is manufactured by Vital Images Inc., Plymouth, MN.

New software programs have been developed to enhance pre-, intra- and postoperative anatomical analysis using a single software platform.^{2,3} Currently available commercial software has similar tools, such as endocranial navigation, image rotation and translation, image adjustment, multiplanar and 3D reconstructions and linear and angular measurements. However, these programs use different reconstruction algorithms and/or methods of measurement ultimately intended to aid professionals in formulating more accurate maxillofacial diagnosis and treatment plans. The reconstruction pattern may be determined by surface rendering or volumetric rendering as previously investigated,^{10,24} although the evaluation of patterns of linear measurement remains unclear.

Different linear measurement methods are also available: linear analysis over the 3D reconstructed images (OsiriX software) and 3D linear analyses [considered as the real 3D measurement (Vitrea software)].

Using OsiriX software, the worst results in our study were found when the pterygoid bone was analysed and found to be on the left length of the lateral plate of the pterygoid process (LLpPtg L). The results presented differences of 1.66 and 2.54 mm from the physical measurement and a moderate correlation coefficient in inter-examiner analysis, which can compromise the surgical result. In agreement to our results, Ueki *et al*¹¹ stated that the measurement position affects the measurement thickness of the ptergomaxillary region, suggesting that it could induce unexpected fractures of the ptergomaxillary region. We believe that these difficulties arose because the linear measurements using OsiriX software were obtained only over a single view of the 3D reconstructed image, and all the measurements whose points require different translation and rotation to be identified, such as those involved in the pterygoid process, could not be easily identified and were therefore not considered to be sufficient for Le Fort I osteotomy pre-operative planning. The OsiriX software tested in this study (v. 1.2 64-bit) was not the latest version available. Manufacturers frequently launch updated programs with new tools, and newer versions may present better results than those found.

Vitrea software results demonstrated high agreement with the gold standard (dry skull measurements), as corroborated by our results in agreement with previous publications.^{7–9,21,23} Intra- and interexaminer analyses demonstrated relevant results for all anatomic structures. The worst results found using Vitrea software showed a major difference of 0.18 mm for all cranio-metric measurements. After performing the statistical analysis, we could state that the results found for linear 3D measurements using Vitrea were precise and accurate, showing no statistical difference in any of the measurements in comparison with the gold standard. The similarity of the results found for linear measurements using Vitrea software shows that these measurements were reliable enough to be applied when performing real 3D measurements for Le Fort I osteotomy planning.

Moreira *et al*,⁸ using CBCT and Vitrea software, found no statistically significant difference between the

Table 7 Comparison between mean value for OsiriX and gold standard

Sample	Data analysis	ANS-PNS	LNW R	LNW L	LPtg R	LPtg L	TPtg R	TPtg L	LLpPtg R	LLpPtg L	LMpPtg R	LMpPtg L
Sample 1	Mann–Whitney U	87.5	89.0	88.0	77.0	89.0	48.0	61.5	71.0	79.0	95.0	102.0
	Z	−1.280	−1.222	−1.261	−1.680	−1.223	−2.789	−2.273	−1.910	−1.604	−0.993	−0.726
Sample 2	p-value	0.201	0.222	0.207	0.093	0.221	0.005	0.023	0.056	0.109	0.321	0.468
	Mann–Whitney U	93.0	93.0	98.0	83.0	81.5	50.0	59.5	58.0	55.5	108.0	106.0
	Z	−1.070	−1.069	−0.878	−1.451	−1.509	2.713	−2.350	−2.406	−2.503	−0.497	−0.573
	p-value	0.285	0.285	0.380	0.147	0.131	0.007	0.019	0.016	0.012	0.620	0.567

ANS, anterior nasal spine; L, left; LNW, length of the lateral nasal wall; LLp, length of the lateral plate; LPtg, length of the pterygoid process; PNS, posterior nasal spine; R, right; TPtg, thickness of the junction between the pterygoid process and the tuberosity of the maxillary.

Sample 1, the two initial observations of the examiners; Sample 2, two subsequent observations.

OsiriX 1.2 64-bit is manufactured by Pixmeo, Geneva, Switzerland.

physical and the CBCT-based linear and angular measurements. Most of the publications in related literature did not describe the measurement method that produced different results. Periago *et al*²⁵ compared the accuracy of linear measurements made on a CBCT obtained from the 3D surface-rendered volumetric image using Dolphin 3D imaging (Dolphin Imaging, Chatsworth, CA) with direct measurements made on human skulls. They concluded that many linear measurements may be significantly different, statistically speaking, from the anatomic dimensions. Furthermore, some of these measurements are considered to be sufficiently accurate from a clinical standpoint for craniofacial analyses. In agreement with this statement, Berco *et al*²⁶ used the same software and concluded that linear measurements made from CBCT produce clinically accurate and reliable 3D linear measurements with an accuracy level limited in part to voxel size and method error.

Lagravère *et al*²⁷ evaluated the accuracy of linear and angular measurements in 3D CBCT images and found that the mean measurement error was <1 mm and 1° from the gold standard. These authors re-emphasized the need to use quantitative analyses to obtain this kind of high quality image and assumed that this error factor was an acceptable result; however, we believe that 1 mm is a considerable distance when the posterior osteotomy of the maxilla is being performed, especially near the descending palatine artery. These quantitative analyses are very important in operator planning to prevent serious complications and decrease procedure morbidity.

The findings of our study showed that linear measurements obtained from software allowing real 3D measurement (Vitre software) in comparison with those obtained from software that requires these measures to be made over 3D reconstruction images (OsiriX software), present statistically significant differences. The real 3D measurements performed by Vitrea software were considered to be more accurate for image manipulation and orthognathic surgical planning.

In conclusion, the 3D linear measurements for Le Fort I osteotomy vary depending on the software used. Vitrea may be considered as precise and accurate, insofar as it was able to perform all the 3D measurements. On the other hand, linear measurements performed over the 3D CBCT images, using OsiriX software, were not successful in producing accurate linear results for Le Fort I osteotomy.

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