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Reproducibility of Linear Measurements Performed with 3-D Cone Beam Computed Tomography: Scan Reconstructions in Region of Pterygomaxillary Junction

Reproduktywność pomiarów liniowych wykonywanych w obszarze połączenia szczękowego-skrzydłowego na podstawie rekonstrukcji otrzymanych dzięki badaniu CBCT

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A – research concept and design; **B** – collection and/or assembly of data; **C** – data analysis and interpretation; **D** – writing the article; **E** – critical revision of the article; **F** – final approval of article

Abstract

Background. Pterygomaxillary dysjunction is the most dangerous part of Le Fort I osteotomy. Preoperative evaluation of the patient's anatomy in 3D imaging software may help to choose an appropriate surgical approach and minimize the risk of the operation.

Objectives. The aim of this study was to evaluate the reproducibility of linear measurements performed at the pterygomaxillary junction using open source software.

Material and Methods. The study population consisted of 101 patients who underwent a CBCT examination for reasons independent of this study. Eight anatomical landmarks in the pterygomaxillary junction were pre-defined to measure the thickness and length of this structure. Linear measurements between the landmarks were performed in duplicate by two independent observers over 14 days. The data was evaluated using Netfabb Basic Studio (Netfabb Company, Parsberg, Germany). An analysis of variance (ANOVA) studied the influence of certain factors (side, observer, and repetition) on the accuracy of the measurements.

Results. The mean value of all the valid measurements was 2.76 mm for thickness and 16.71 mm for the length of the pterygomaxillary junction. ANOVA showed no inter-observer bias. None of the observers reported statistically significantly higher or lower values than the other observer ($p > 0.05$). The intra-observer reproducibility was better than the inter-observer reproducibility of the measurements. The intra- and inter-observer reproducibility analyzed for log-transformed absolute values of differences between the measurements was very good (< 0.5 mm mean difference for linear values reconstructed from the log). The results were from a relatively large population and offered useful and reproducible measurements using open source software during the planning of orthognathic procedures.

Conclusions. The results confirmed the reproducibility of the measurements. This method may be used during the diagnostics and planning of Le Fort I osteotomy. We also propose further evaluation of open-source software programs. Their comparison may help standardize the planning of orthognathic procedures (**Dent. Med. Probl. 2016, 53, 3, 320–331**).

Key words: orthognathic surgery, Le Fort I osteotomy, pterygomaxillary separation, preoperative examination.

Słowa kluczowe: chirurgia ortognatyczna, osteotomia szczęki typu Le Fort I, separacja szczękowo-skrzydłowa, badanie przedoperacyjne.

Orthognathic surgeries are standard procedures to correct skeletal angle class II and III deformities, dentomaxillofacial deformities, mandibular laterognathia, and maxillofacial asymmetries [1–4]. There are three standard procedures used in orthognathic surgery: Le Fort I osteotomy, bilateral sagittal split osteotomy (BSSO) and genioplasty. Von Langenbeck first described osteotomy of the Le Fort I level for the removal of nasopharyngeal polyps in 1859. In 1901, French physician Rene Le Fort [5] described the most common classification of such osteotomies. He analyzed the patterns of maxillofacial fractures. Wassmund was probably the first who performed total maxillary osteotomy to correct maxillofacial deformities. As a result, the Le Fort I osteotomy is now widely known and has become one of the most popular procedures to manage maxillary deformities.

Orthognathic surgery offers significant improvement of function via a stomatognathic apparatus. It also improves aesthetic outcomes [6, 7]. However, as with any surgical procedure, various preoperative, intraoperative, and postoperative complications can occur [8]. Recently, a published systematic review (SR) of complications in orthognathic surgery revealed the presence of many varied complications associated with this branch of surgery [8]. Manipulation of the bones during the operation may inadvertently cause damage to the vessels and nerves in this region, resulting in serious complications [8–10]. The anatomical region which is especially important is the pterygomaxillary junction (Fig. 1, 2). Unfavorable dysjunction of the maxilla and sphenoid bone in this area may result in inadvertent fracture even to the base of the skull. During this maneuver, there is a risk of injury to cranial nerve II, III, and VI. There are also cited cases of V1 and V2 [11, 12] and X, XI, and XII cranial nerve injuries [13]. Blood vessel damage have also been attributed to unfavorable dysjunction of the pterygoid plates from the posterior maxillary wall. The dimension of thickness and length of the pterygomaxillary junction have significant influence on the success of its separation. An increased thickness of the pterygomaxillary junction predisposes it to fractures at the greater palatine foramen [5, 9]. On the other side one of the potential risk factors for pterygoid plate fracture is a thin and short pterygomaxillary junction [5]. While performing pterygomaxillary dysjunction, the surgeon can use a handle maneuver, osteotome or oscillating saw. The first technique may be used in a very gentle way in patients with a thin junction between the maxilla and sphenoid bone. In cases of a thick junction, osteotomes and oscillating saw are necessary. The use of osteotomes carries a risk of nerve or blood vessel injury. In patients with a greater thickness of the pterygoid plates, there is an expected dysjunction of the pterygoid plate from the maxillary tuberosity. Such separation is possible to achieve with osteotomy through maxillary tuberosity [5]. This explains why awareness of an individual patient's anatomy is so important before surgery. An uncomplicated operative course is the preferable result, but an appropriate preoperative evaluation of the posterior maxillary region is also required.

In addition, the variability of pterygoid plate fractures may influence the exact further positioning of the maxilla. An understanding of the pterygomaxillary junction region helps to prevent blood loss and unfavorable fractures during the Le Fort I

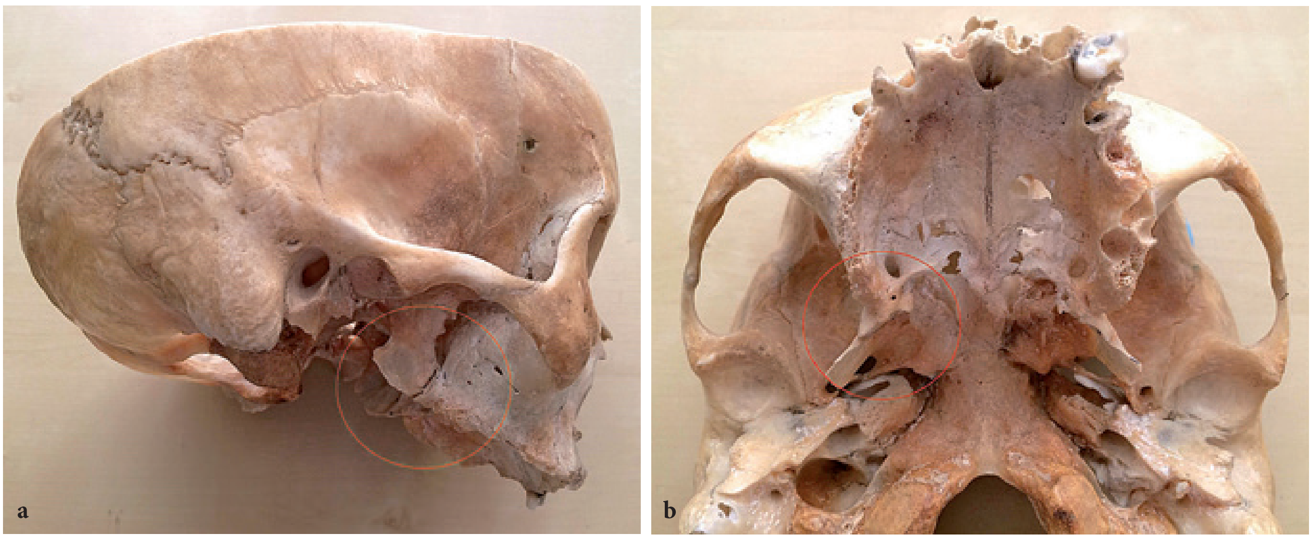
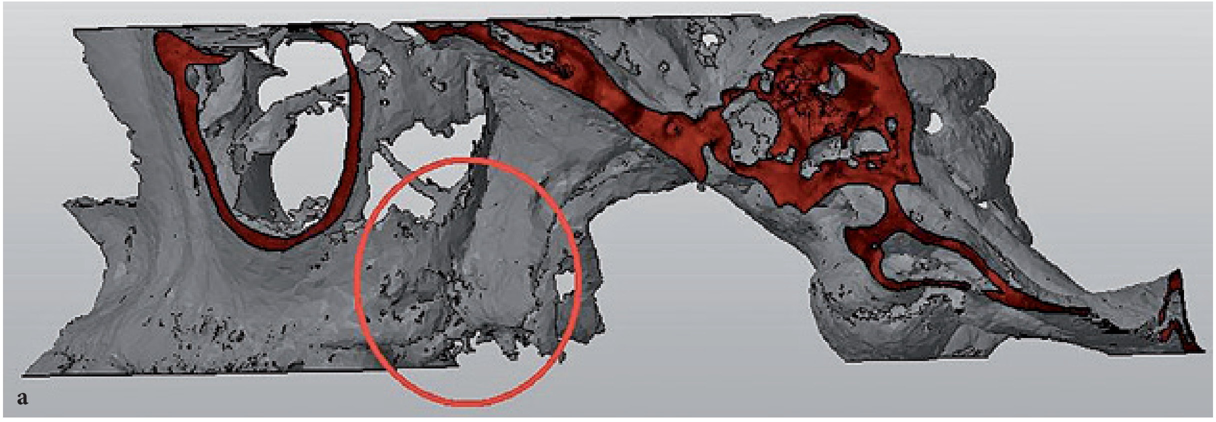


Fig. 1a–b. Pterygomaxillary junction. The anatomical region which is especially important during Le Fort I osteotomy performed in orthognathic surgery



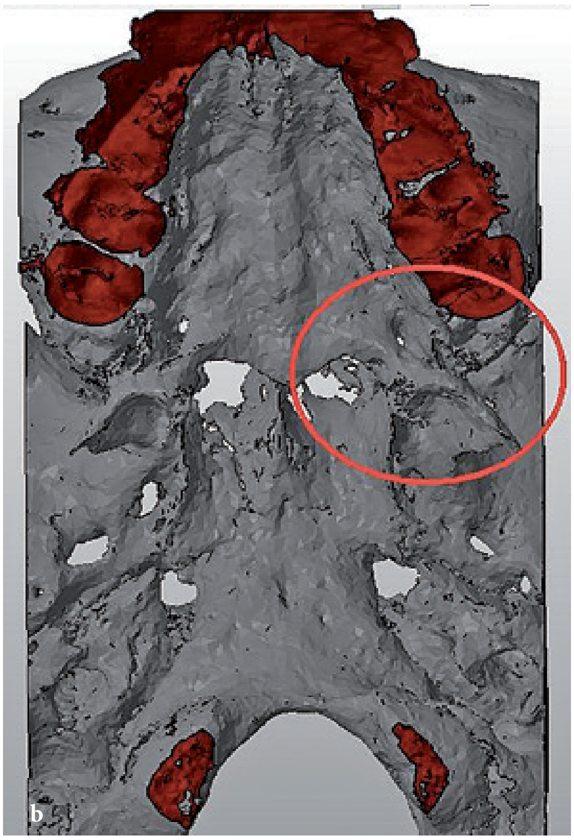


Fig. 2a–b. The area of the pterygomaxillary junction presented in Netfabb Basic Studio. Images generated from CBCT (cone beam computed tomography)

osteotomy. The success of this procedure depends on precise and accurate preoperative analysis.

Cone beam CT (CBCT) offers diagnostically valuable information about the three-dimensional (3D) morphology of anatomical structures. Modern imaging software allows for endocranial navigation, image rotation and translation, brightness and contrast adjustment, multiplanar and 3D reconstructions, and linear and angular measurements [14]. These can be used for appropriate planning, which predicts outcomes related to the orthognathic surgery [15]. Surgeons are obligated to increase the safety of orthognathic surgery procedures and to minimize the risk of complications [8]. Therefore, we evaluated the reproducibility of linear measurements performed in pterygomaxillary junctions using open source software for pre-orthognathic surgery diagnostics. The null hypothesis was that the linear measurements performed on 3D CBCT surface reconstructions are reproducible. The aim of this study was to answer the clinical question: "Can we use 3D CBCT surface reconstructions for the planning of Le Fort I osteotomy?".

Materials and Methods

Sample

The study population consisted of 101 Caucasians (58 women and 43 men) aged between 20 and 40 years and referred to the Private Unit of Maxillofacial Radiology for reasons independent of our study. Approval was granted by the Institutional Review Committee/Human Specimens Committee (KB-0012/42/05/2014). The inclusion criteria were age between 20 and 40 years and no history of trauma or bone disease. Exclusion criteria included age other than determined and any trauma or bone disease in the medical records.

Data collection

All patients underwent a CBCT examination (I-CAT® Cone Beam 3D Dental Imaging System, Imaging Sciences International, Hatfield, USA) for reasons independent of our study. All CT data was acquired in a standard head position. Images were recorded at 0.25 mm voxel size. The field of view (FOV) was a 20 cm height and 16 cm diameter cylinder. This data was recorded and stored in DICOM (Digital Imaging Communication in Medicine) format. Afterward, surface-rendering models

Table 1. Description of the pre-defined craniometric anatomical structures and the following linear measurements

Anatomical structure	Description
Length of the right pterygomaxillary junction (PMJ right)	distance between the highest and the lowest points of bone fusion of the pterygoid process and tuberosity of the maxilla on the right side of the patient (PMJ)
Length of the left pterygomaxillary junction (PMJ left)	distance between the highest and the lowest points of bone fusion of the pterygoid process and tuberosity of the maxilla on the left side of the patient (PMJ)
The smallest thickness of the right pterygomaxillary junction (thickness right)	the shortest distance between the most distal point of the maxillary sinus wall and the most anterior point of the pterygoid fossa on the right side of the patient
The smallest thickness of the left pterygomaxillary junction (thickness left)	the shortest distance between the most distal point of the maxillary sinus wall and the most anterior point of the pterygoid fossa on the left side of the patient

were generated in Netfabb® Basic Studio (Netfabb, Parsberg, Germany) installed in an independent workstation running the Windows 7 Home (Microsoft, Redmond, USA) operating system with 16 GB DDR RAM at 1600 Mhz. Linear measurements of the smallest thickness of the pterygomaxillary junction (thickness) and the length of pterygomaxillary junction (PMJ) were obtained using the anatomical landmarks described in Table 1. The selected landmarks were chosen because of their relevance in the planning of the Le Fort I osteotomy, especially the pterygomaxillary dysjunction.

Two observers participated in this study. The observers identified and confirmed the desired location of marked structure points using an arrow and available software tools (rotation, translation, zoom and transparency) (Fig. 3a–b, 4). This allowed the observers to analyze images on different spatial planes to confirm the chosen anatomical landmarks. All measurements (n = 4) were performed by both examiners for each patient (twice each) with a 14-day time interval to ensure intra-examiner and inter-examiner reliability. The 3D coordinates (x, y and z) for each cranial landmark were automatically generated with the software. These coordinates were then converted to distances (thickness and PMJ) between the respective points, saved in XLSX format and copied to Microsoft Excel 2010 spreadsheets (Microsoft Corporation, Redmond, USA). There were 1616 measurements.

Statistical Methods

All measurements were collected in one Excel spreadsheet. First, the data was inspected to identify and exclude coarse errors that were identified when one measurement of four (2 observers x 2 series) was very different from the others. Detailed analysis showed that the coarse errors were caused by invalid location of the cranial landmark or use of the wrong software tool for performing the measurement. Such false data was excluded from further analysis. The data was then inspected for minor errors caused by mistakes in the process of manual rewriting of the data from Netfabb software to the spreadsheet or by comparison with the original values in the software. The value was corrected when such errors were found. Repeated measures analysis of variance (ANOVA) was performed to evaluate the precision of measurements and to identify the sources of imprecision. Reproducibility of linear measurements was analyzed to assess the usefulness of our method in planning orthognathic surgeries. For analysis of intra-observer reproducibility, absolute values of differences between two measurements performed by each observer were transformed logarithmically (a constant value between 0 and 0.05 mm was added before transformation to achieve the most normal distribution of transformed values). The arithmetic mean of these two values (one for each observer) was calculated for each patient and side. For the analysis of inter-observer reproducibility, four absolute values of differences were calculated: observer 1, measurement 1 – observer 2, measurement 1; observer 1, measurement 1 – observer 2, measurement 2; observer 1, measurement 2 – observer 2, measurement 1; observer 1, measurement 2 – observer 2, measurement 2. These were transformed logarithmically (as specified above) and the arithmetic mean of these four values was calculated for each patient and side. The mean value has a 95% confidence interval and was calculated for these log-transformed values. The values were then transformed exponentially, and the constant described above was subtracted to reconstruct the mean values and 95% CI of errors in linear units (mm).

Results

The percentage of data with coarse errors was 1.49%; these were excluded from further analyses as invalid. The percentage of data with mi-

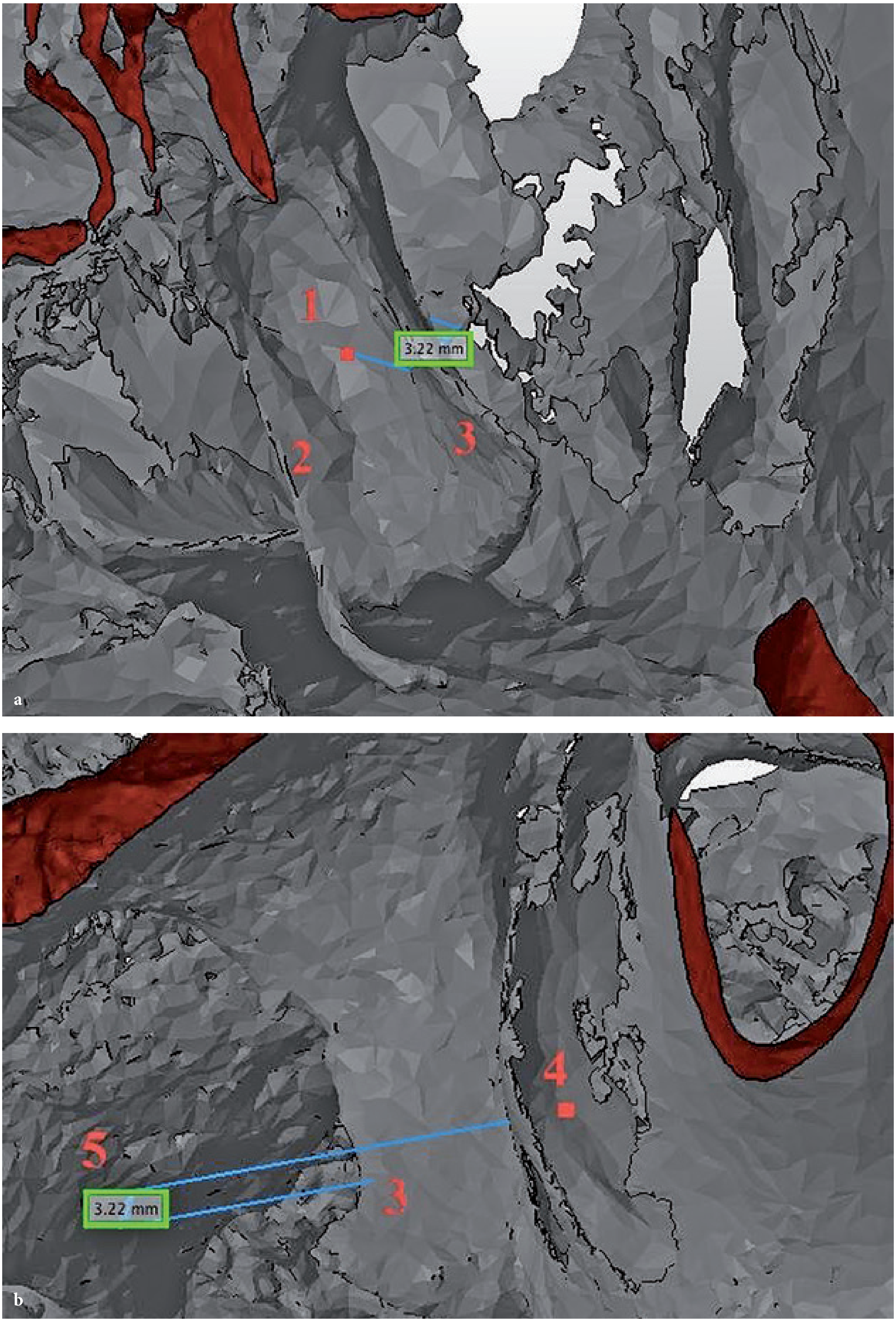


Fig. 3a–b. Linear measurements of the smallest thickness of the pterygomaxillary junction (thickness) were identified and confirmed using an arrow and available software tools (rotation, translation, zoom and transparency). 1 – the most anterior point of the pterygoid fossa; 2 – medial plate of pterygoid process of sphenoid bone; 3 – lateral plate of pterygoid process of sphenoid bone; 4 – the most distal point of the maxillary sinus wall; 5 – measurement

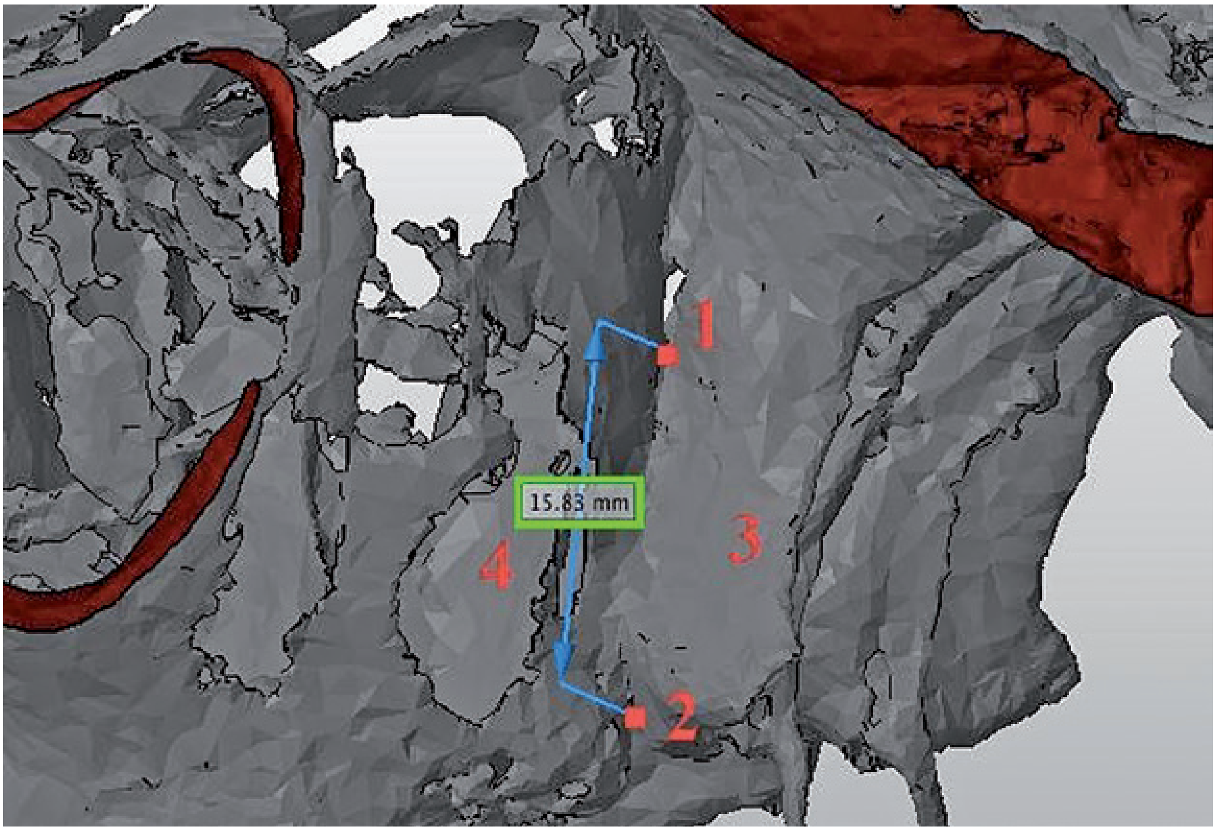


Fig. 4. Linear measurements of the length of the pterygomaxillary junction (PMJ) were identified and confirmed using an arrow and available software tools (rotation, translation, zoom and transparency). 1 – the highest point of bone fusion of the pterygoid process and tuberosity of the maxilla; 2 – the lowest point of bone fusion of the pterygoid process and tuberosity of the maxilla; 3 – lateral plate of the pterygoid process of the sphenoid bone; 4 – measurement

nor errors was 0.25%, and these values were corrected. The descriptive statistics obtained from all measurements was performed in 96 patients with valid data presented in Tables 2 and 3. Analysis of variance (ANOVA) showed no bias for the results of both observers, i.e. none of them reported statistically significantly higher or lower values than the other one ($p = 0.10$ for thickness; $p = 0.20$ for PMJ) (Table 4 and 5). There was no bias for the results reported in the first or second series of thickness measurements ($p = 0.24$, Table 4). Such bias was found for PMJ values, and these were generally lower in the second series of measurements ($p = 0.0098$, Table 5).

However, a significant interaction was found for observer*repetition factor (Table 4). This means that one observer had bias in reporting lower thickness values in the second measurement than in the first. The other reported lower values in the first measurement (Fig. 5 and 6). Higher ANOVA SS (sum of squares) values for "observer error" than for "repetition error" (both for thickness and PMJ) implies that inter-observer differences were higher than intra-observer differences (Table 4 and 5). It is worth noting that thickness and PMJ lengths were significantly higher on the left than on the right side (Table 4 and 5) even though the differences were small (Table 2 and 3). However, the high SS value of "side error" reflects the variability of human anatomy resulting in random differences of thickness and PMJ lengths between the patient's sides. The mean value of all valid measurements was 2.76 mm for thickness and 16.71 mm for length of PMJ. The mean intra-observer difference was 0.34 mm for thickness and 0.24 mm for PMJ (Table 6). The mean inter-observer difference was 0.40 mm for thickness and 0.22 mm for PMJ (Table 7). The mean error of both measured parameters lesser than 1mm showed high repeatability of measurements.

Discussion

Le Fort I osteotomy has become the procedure of choice for managing maxillary deformities. A posterior split of the maxilla – so-called pterygomaxillary dysjunction – is the most vulnerable part of this procedure. We studied the region of the pterygomaxillary junction because the pterygoid process of the sphenoid bone includes important vascular structures and presents a high incidence of unplanned fractures. Aforementioned factors like the dimensions of thickness and length

Table 2. Mean values with their standard error and the 95% confidence interval of thickness measurements for each combination of side, observer and repetition

Combination number	Side	Observer	Repetition	Mean Value	Standard Error	95% confidence interval		N
						lower bound	upper bound	
2	R	1	2	2.662	0.114	2.434	2.889	96
3	R	2	1	2.687	0.101	2.486	2.888	96
4	R	2	2	2.537	0.0896	2.359	2.715	96
5	L	1	1	2.886	0.120	2.648	3.124	96
6	L	1	2	3.104	0.125	2.855	3.353	96
7	L	2	1	2.976	0.111	2.756	3.195	96
8	L	2	2	2.677	0.091	2.498	2.857	96

Table 3. Mean values with their standard error and the 95% confidence interval of PMJ measurements for each combination of side, observer and repetition

Combination number	Side	Observer	Repetition	Mean Value	Standard Error	95% confidence interval		N
						lower bound	upper bound	
1	R	1	1	16.523	0.270	15.988	17.059	96
2	R	1	2	16.444	0.256	15.936	16.951	96
3	R	2	1	16.555	0.260	16.039	17.071	96
4	R	2	2	16.37	0.255	15.864	16.876	96
5	L	1	1	16.982	0.272	16.443	17.522	96
6	L	1	2	17.010	0.277	16.460	17.560	96
7	L	2	1	16.985	0.274	16.441	17.530	96
8	L	2	2	16.834	0.286	16.267	17.401	96

Table 4. The repeated-measures analysis of variance (ANOVA) for thickness

Factor	SS	df	MS	F	p
Side	15.442	1	15.442	10.259	0.0019
Error	142.998	95	1.505		
Observer	1.888	1	1.888	2.743	0.10
Error	65.405	95	0.689		
Repetition	0.437	1	0.437	1.382	0.24
Error	30.045	95	0.316		
Side*Observer	0.921	1	0.921	2.368	0.13
Error	36.954	95	0.389		
Side*Repetition	0.011	1	0.011	0.039	0.84
Eerror	27.221	95	0.287		
Observer*Repetition	5.968	1	5.968	15.139	0.0002
Error	37.450	95	0.394		
Side*Observer*Repetition	1.289	1	1.289	4.685	0.03
Error	26.131	95	0.275		

of the pterygomaxillary junction have a great influence on the success of bone separation. An increased thickness of the pterygomaxillary junction predisposes it to fractures at the greater palatine foramen [5, 9]. On the other side, one of the potential risk factors for pterygoid plate fracture is a thin and short pterygomaxillary junction [5]. Down-fracture of the maxilla, performed in a very

Table 5. The repeated-measures analysis of variance (ANOVA) for PMJ

Factor	SS	df	MS	F	p
Side	44.213	1	44.213	5.662	0.019
Error	741.847	95	7.809		
Observer	0.552	1	0.552	1.645	0.20
Error	31.877	95	0.336		
Repetition	1.795	1	1.795	6.945	0.0098
Error	24.556	95	0.259		
Side*Observer	0.206	1	0.206	0.822	0.37
Error	23.843	95	0.251		
Side*Repetition	0.242	1	0.242	0.918	0.34
Error	25.052	95	0.264		
Observer*Repetition	0.971	1	0.971	3.139	0.08
Error	29.389	95	0.309		
Side*Observer*Repetition	0.063	1	0.063	0.201	0.66
Error	29.674	95	0.312		

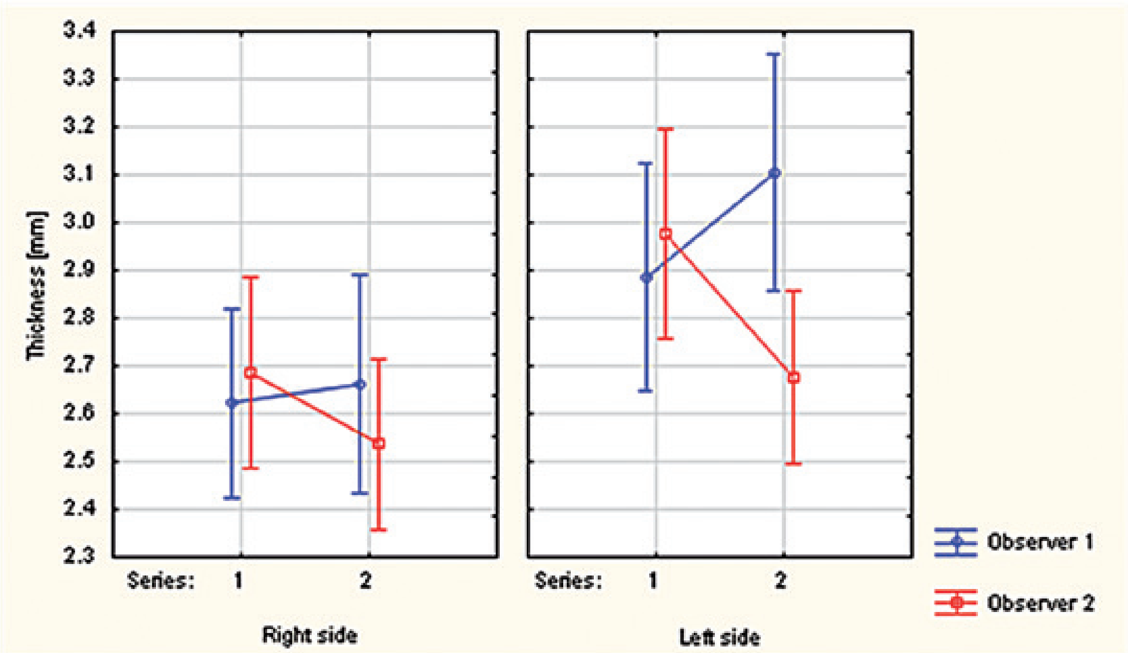


Fig. 5. Graphical presentation of ANOVA results for thickness. Mean values with 95% confidence intervals are shown for each combination of side, observer and series of measurements

gentle way with a handle maneuver, is supposed to be safer than the procedure with the use of osteotome. In patients with a greater thickness of the pterygoid plates, there are alternative options, for instance, dysjunction of the pterygoid plate from the maxilla through maxillary tuberosity [5]. Many times, the choice of surgical approach is based on the individual patient's condition. That is the reason why an accurate preoperative investigation of the patient's anatomy is so important during the planning process.

The dimensions of the pterygomaxillary junction length have been measured by several researchers. It has been evaluated by direct inspection [14–18] as well as with 3D CBCT reconstruction images [14, 15, 18]. However, these programs use different reconstruction algorithms or different methods of measurement, or both. There are different tools to manipulate the images. Gaia et al. [14] analyzed several pieces of software and techniques of measurements. They showed that linear craniofacial measurements obtained with multi-slice

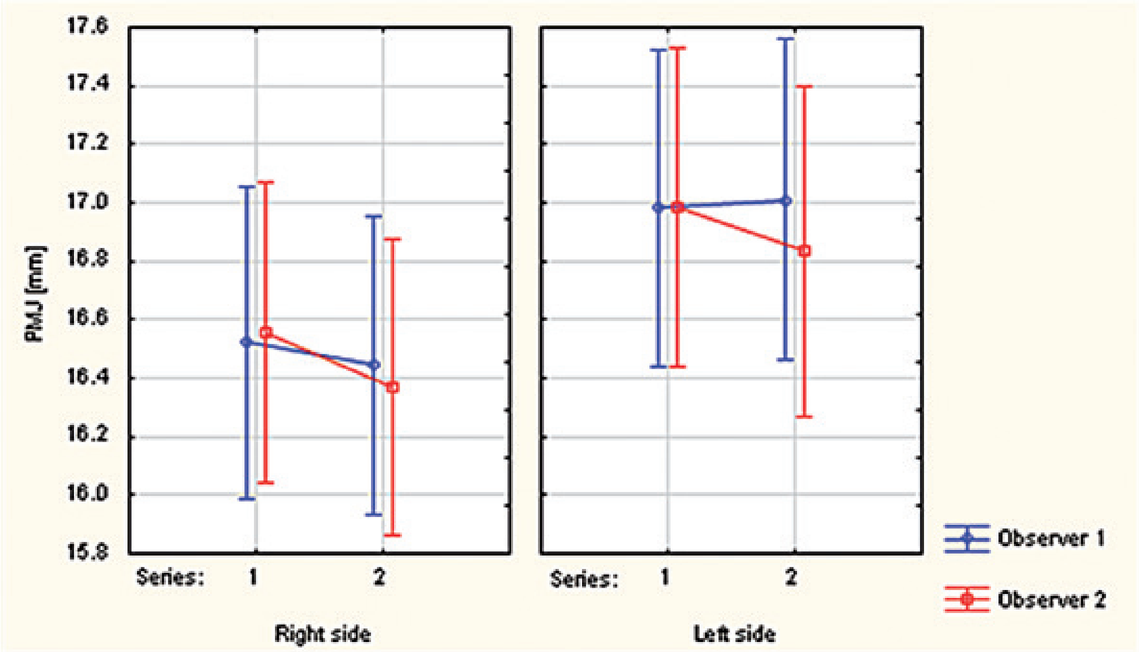


Fig. 6. Graphical presentation of ANOVA results for PMJ. Mean values with 95% confidence intervals are shown for each combination of side, observer and series of measurements

Table 6. Intra-observer mean linear difference reconstructed from the log with the 95% confidence interval for measurements of Thickness and PMJ

Site	Mean linear difference reconstructed from log (mm)	95% confidence interval for mean linear difference (mm)	
		lower bound	upper bound
Thickness	0.343	0.304	0.387
PMJ	0.246	0.217	0.278

Table 7. Inter-observer mean linear difference reconstructed from the log with the 95% confidence interval for measurements of Thickness and PMJ

Site	Mean linear difference reconstructed from log (mm)	95% confidence interval for mean linear difference (mm)	
		lower bound	upper bound
Thickness	0.400	0.356	0.448
PMJ	0.221	0.196	0.249

computed tomography (MSCT) and cone beam computed tomography (CBCT) are precise and accurate versus dry skull measurements, which is considered the gold standard.

Other works by this group compared different imaging software using 3D CBCT images. Vitrea Software was the most accurate and precise. The authors explained that the variability of measurements gained in the Dolphin® Imaging Software may be caused by the fact that even though the anatomical landmarks may be identified by multiplanar guide, the selection of the initial and final points must be made on the same spatial plane. This comprises the identification and measurement of anatomical landmarks [18]. Power et al. [19] also found weaknesses in the Dolphin Imaging Software. They concluded that software errors in the calculations result in clinically significant errors in measurements. Periago et al. [20] showed that many linear measurements using Dolphin Imaging Software could be statistically different from the anatomic dimensions. In the other program, the examiner had to trace the line between the anatomical landmarks directly on the 3D reconstructed images to join the points previously marked in the multiplanar reconstructed (MPR) images and then obtain the measurements [15].

Gaia et al. [14, 15, 18] reported very valuable information in their series of articles. The study population consisted of 11 dry skulls submitted for CBCT. Measurements based on the physical data via digital calipers are the gold standard in anatomy evaluation. In statistical analysis, they compared intraexaminer and interexaminer correlation coefficients. The results were in moderate to excellent agreement, and the authors emphasized the need to compare different 3D measurement techniques and software.

In our research, we used another software program – the open-source Netfabb Basic Studio. Our population consisted of 101 patients submitted for CBCT. The results confirmed the findings of Gaia et al. [14, 18]. In a large group of patients with the free software, we proved the reproducibility of linear measurements made with Netfabb Basic Studio. Our statistical analysis showed mean differences of measurements less than 0.5 mm. Gaia et al. [15] found that the mean differences between the physical and the 3D-CBCT linear measurements are less than 1 mm.

Ueki et al. [21] described the difficulty in locating the anatomical landmarks and performing measurements in the pterygoid region. Nagasaka et al. [22] proved that the more closely located the two landmarks are, the greater the measurement error may appear. Kanazawa et al. [5] and Ueki et al. [9] revealed that increased thickness of the pterygomaxillary junction predisposes it to fractures on the greater palatine foramen. The authors concluded that potential risk factors for pterygoid plate fracture are: thinner pterygomaxillary junction, longer maxillary tuberosity, male gender and increased age [5]. In patients with greater thickness of pterygoid plates, the surgeon may expect appropriate dysjunction of the pterygoid plate from the maxillary tuberosity. The unpredictability of pterygoid plate fractures may interfere with exact placement of the maxilla, particularly in posterior impaction and setback movements.

Apinhasmit [acc. 14] suggested that synostosis rather than pterygomaxillary fissure confirms the failure to achieve complete separation at the pterygomaxillary junction. The presence of synostosis at the pterygomaxillary fissure changes its hardness. The failure of exact separation of the pterygomaxillary fissure was presented by Cheung et al. [16]. They confirmed the 12% rate of occurrence of synostosis in their population group [16]. Preoperative radiography is currently obligatory. Radiographic analysis is crucial not only to ensure the accuracy of treatment planning, but also to evaluate anatomical structures and predict possible alterations that may lead to intraoperative and postoperative complications [17]. The introduction of CBCT allowed for early recognition of possible anatomical differences. New software applications have been developed to enhance anatomical analysis in a single software platform [18]. In this research, regardless of manual selection of craniometric landmarks, both observers offered repeatable results.

Analysis of variance confirmed no statistically significant bias in a large sample between measurements of two observers (Table 4 and 5). ANOVA also showed a statistically significant bias between the first and second series of measurements of PMJ ($p = 0.0098$). However, random differences between the first and second repetitions of one observer ($SS = 24.556$) were still smaller than the random differences of measurements made by the two different observers ($SS = 31.877$). The estimation of differences within repeated measurements expressed in millimeters by one observer (intra-observer) and by two observers (inter-observer) showed high repeatability. The mean intra-observer and inter-observer error was smaller than 0.5 mm for both measured parameters (Table 6 and 7).

According to the classification proposed by Olszewski et al. [23], all our measurements may be classified in Group 1 with very high reproducibility (mean error < 1 mm). This result assumes that surgeons using this method in Netfabb Basic Studio can gain reproducible measurements. One additional advantage is the availability of the program – Netfabb Basic Studio is an open-source program. It is completely free for the investigator with access to computer workstations and the internet. This could be a step to propagate 3D preoperative patient evaluation based on CBCT. The use of our method and open-source software allows clinicians to simply compare their patients to this cohort. We evaluated PMJ in a large group of Caucasians, and this could be a reference point to assess the increased difficulty of pterygomaxillary dysjunction [5]. As mentioned before, increased awareness of anatomical structures and their relationship in the region of the pterygomaxillary junction may minimize risk of injury to the nerves and arteries and achieve safe and effortless maxillary down-fracture.

There are also some limitations to using the open-source software. Free versions often have no access to some tools and program options. However, linear and angular measurements are usually available. The other limitation is accuracy (differences between the measured and real distance). This is independent of reproducibility. The pay platforms currently available are generally well validated with proven accuracy. Most open-source programs are still not validated. We recommend evaluating other open-source programs for their accuracy and reproducibility. It is worth noting that the rate of coarse errors was more than 1%. When a coarse error appears, the measurement should be repeated, preferably by another observer, to minimize its impact on the general result. The influence of minor errors was smaller

(0.25%), even though the automatic export of data from the software to a database or spreadsheet should be standard practice.

Conclusion

According to the literature, preoperative evaluation of the pterygomaxillary junction region is necessary before orthognathic surgeries [14, 15, 18]. In our results, the differences between measurements less than 1 mm confirmed the null hypothesis and showed good precision as well as high reproducibility. This method can be used during diagnostics and planning of Le Fort I osteotomy. We propose further evaluation of open-source software programs in 3D CBCT-scan reconstructions. This comparison may help standardize the planning of orthognathic procedures.

References

[1] Ow A., Cheung L.K.: Skeletal stability and complications of bilateral sagittal split osteotomies and mandibular distraction osteogenesis: An evidence-based review. J. Oral Maxillofac. Surg. 2009, 67, 2344–2353.
[2] Ruiz L.P., Lara J.C.: Facial nerve palsy following bilateral sagittal split ramus osteotomy for setback of the mandible. Int. J. Oral Maxillofac. Surg. 2011, 40, 884–886.
[3] Chrcanovic B.R., Custódio A.L.: Optic, oculomotor, abducens, and facial nerve palsies after combined maxillary and mandibular osteotomy: case report. J. Oral Maxillofac. Surg. 2011, 69, e234–241.
[4] Rai K.K., Shivakumar H.R., Sonar M.D.: Transient facial nerve palsy following bilateral sagittal split ramus osteotomy for setback of the mandible: A review of incidence and management. J. Oral Maxillofac. Surg. 2008, 66, 373–378.
[5] Kanazawa T., Kuroyanagi N., Miyachi H., Ochiai S., Kamiya N., Nagao T., Shimozato K.: Factors predictive of pterygoid process fractures after pterygomaxillary separation without using osteotome in Le Fort I osteotomy. Oral Surg. Oral Med. Oral Pathol. Oral Radiol. 2013, 115, 310–318.
[6] Nowak R.: Historical outline of orthognathic surgery. Dent. Med. Probl. 2014, 51, 131–135 [in Polish].
[7] Vallino L.: Speech, velopharyngeal function, and hearing before and after orthognathic surgery. J. Oral Maxillofac. Surg. 1990, 48, 1274–1281.
[8] Jędrzejewski M., Smektała T., Sporniak-Tutak K., Olszewski R.: Preoperative, intraoperative, and postoperative complications in orthognathic surgery: a systematic review. Clin. Oral Investig. 2015, 19, 969–977.
[9] Ueki K., Hashiba Y., Marukawa K., Nakagawa K., Okabe K., Yamamoto E.: Determining the anatomy of the descending palatine artery and pterygoid plates with computed tomography in Class III patients. J. Craniomaxillofac. Surg. 2009, 37, 469–473.
[10] Li K.K., Meara J.G., Alexander A. Jr.: Location of the descending palatine artery in relation to the Le Fort I osteotomy. J. Oral Maxillofac. Surg. 1996, 54, 822–827.
[11] Kim J.W., Chin B.R., Park H.S., Lee S.H., Kwon T.G.: Cranial nerve injury after Le Fort I osteotomy. Int. J. Oral Maxillofac. Surg. 2011, 40, 327–329.
[12] Chrcanovic B.R., Custodio A.L.: Optic, oculomotor, abduces, and facial nerve palsies after combined maxillary and mandibular osteotomy: Case report. J. Oral Maxillofac. Surg. 2011, 69, 234–241.
[13] Baddour H.M., Watson J., Erwin B.J.: Life-threatening hemorrhage from a Le Fort I osteotomy. J. Oral Maxillofac. Surg. 1982, 40, 117–124.
[14] Gaia B.F., Pinheiro L.R., Umetsubo O.S., Costa F.F., Cavalcanti M.G.: Validity of three-dimensional computed tomography measurements for Le Fort I osteotomy. Int. J. Oral Maxillofac. Surg. 2014, 43, 197–203.
[15] Gaia B.F., Pinheiro L.R., Umetsubo O.S., Costa F.F., Cavalcanti M.G.: 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. Dentomaxillofac. Radiol. 2013, 42, 20120178.
[16] Apinhasmit W., Chompoopong S., Methathrathip D., Sangvichien S., Karuwanarint S.: Clinical anatomy of the posterior maxilla pertaining to Le Fort I osteotomy in Thais. Clin. Anat. 2005, 18, 323–329.
[17] Cheung L.K., Fung S.C., Li T., Samman N.: Posterior maxillary anatomy: Implications for Le Fort I osteotomy. Int. J. Oral Maxillofac. Surg. 1998, 27, 346–351.
[18] Gaia B.F., Pinheiro L.R., Umetsubo O.S., Santos Júnior O., Costa F.F., Cavalcanti M.G.: Accuracy and reliability of linear measurements using 3-dimensional computed tomographic imaging software for Le Fort I osteotomy. Br. J. Oral Maxillofac. Surg. 2014, 52, 258–263.
[19] Power G., Breckon J., Sherriff M., McDonald F.: Dolphin Imaging Software: An analysis of the accuracy of cephalometric digitization and orthognathic prediction. Int. J. Oral Maxillofac. Surg. 2005, 34, 619–626.
[20] Periago D.R., Scarfe W.C., Moshiri M., Scheetz J.P., Silveira A.M., Farman A.G.: Linear accuracy and reliability of cone beam CT derived 3-dimensional images constructed using an orthodontic volumetric rendering program. Angle Orthod. 2008, 78, 387–395.
[21] Ueki K., Hashiba Y., Marukawa K., Okabe K., Alam S., Nakagawa K., Yamamoto E.: Assesment of pterygomaxillary separation In Le Fort I osteotomy In class III patients. J. Oral Maxillofac. Surg. 2009, 67, 833–839.
[22] Nagasaka S., Fujimura T., Segoshi K.: Development of a non-radiographic cephalometric system. Eur. J. Orthod. 2003, 25, 77–85.
[23] Olszewski R., Tanesy O., Cosnard G., Zech F., Reychler H.: Reproducibility of osseous landmarks used for computed tomography based three-dimensional cephalometric analyses. J. Craniomaxillofac. Surg. 2010, 38, 214–221.

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