ORIGINAL PAPERS

Dent. Med. Probl. 2016, 53, 3, 309–319
DOI: 10.17219/dmp/62481

© Copyright by Wrocław Medical University and Polish Dental Society
ISSN 1644-387X

ADAM JAWORSKI^{1, A-F}, TOMASZ SMEKTAŁA^{1, A-F}, MARCIN KRÓLIKOWSKI^{2, A, C, F},
KATARZYNA SPORNIAK-TUTAK^{1, A, E, F}, RAPHAEL OLSZEWSKI^{3, A, B, E, F}

How Do Landmark Deviations Affect Angular Measurements? The Concept of Individual Cephalometric Calibration

Jak zmiana położenia punktów cefalometrycznych wpływa na wyniki pomiarów kątowych?
Koncepcja indywidualnej kalibracji cefalometrycznej

¹ Department of Maxillofacial Surgery, Pomeranian Medical University, Szczecin, Poland

² Institute of Manufacturing Engineering, West Pomeranian University of Technology, Szczecin, Poland

³ Oral and Maxillofacial Surgery Research Lab, Department of Oral and Maxillofacial Surgery, Cliniques Universitaires Saint Luc, Université Catholique de Louvain, Belgium

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. Cephalometry is an ancillary test that is widely used in orthodontics and maxillofacial surgery. Any cephalometric analysis is based on measurements performed between manually selected specific landmarks. Any inaccuracies in landmarks selection may bias the results of diagnosis, treatment planning or evaluation of craniofacial growth.

Objectives. The aim of this study was to identify the possible influence of linear landmark deviations on the X and Y axes on angular measurements, and to propose an individual cephalometric calibration concept to increase the landmark selection accuracy.

Material and Methods. A reference cephalometric template was created in GeoGebra software (International GeoGebra Institute, Linz, Austria). Based on the template, the values of the “S”, “N”, “ANS”, “A”, “B”, “Go”, “tgo”, “Pm”, and “Gn” cephalometric landmark locations were modified for 0.5 mm, 1 mm, 2 mm, 3 mm and 4 mm in each direction on the X and Y axis and angular changes were noted.

Results. For all angular measurements, a landmark selection error equal to or greater than 2 mm resulted in a change of more than 1 degree. Finally a four-step process of individual calibration was presented.

Conclusions. Depending on the landmark dislocation direction (horizontal or vertical), the angular measurements can be affected in either a minor or major way. Individual calibration allows for the detection of inaccuracies in the X and Y axis. Detailed analysis of the calibration results makes possible the correction of the selected errors, which could lead to more accurate measurements during cephalometric analysis and the detection of more subtle changes (Dent. Med. Probl. 2016, 53, 3, 309–319).

Key words: calibration, reproducibility of results, cephalometry.

Słowa kluczowe: kalibracja, powtarzalność wyników, kefalometria.

Cephalometry is an ancillary test that is widely used in orthodontics and maxillofacial surgery for the diagnosis, treatment planning and evaluation of craniofacial growth [1–3]. Although opinions about its usefulness vary [3–6], 90% of Amer-

ican orthodontist currently report using it in their practice [7].

Since the introduction of cephalography [8], a number of conventional cephalometric analyses have been developed based mainly on facial

growth physiology [9, 10]. Cephalometric landmarks were primarily chosen to support specific theories, without consideration of their reproducibility. However, reproducibility is important for patient follow-up, communication between clinicians, assessment of treatment outcomes, and the accurate determination of craniofacial growth patterns. Any discrepancy between the inter- or intra-observer selection may bias these procedures. To overcome the inaccuracies and shorten the examination time, cephalometry has evolved from a manual to a computer-aided technique, and some calibration methods have been proposed. The first attempt at calibration was the introduction of coordinatographs in 1980 [11]. The coordinatographs were composed of movable cursors mounted on two straight runners embedded in a circular runner. This construction allowed for linear and angular measurements along the X and Y axes, the registration of landmark coordinates at 0.1 mm and 0.1 degree increments, and the superimposition of different cephalograms. However, calibration with coordinatographs required complex equipment and was still time-consuming compared to fully manual tracing. Later, the development of computer technology allowed coordinatographs to be replaced by specialized software. The use of applications dedicated to cephalometry has thus reduced the time needed for examination [12], facilitated inter-physician communication, and increased the accuracy of cephalogram superimposition. With this approach, three more calibration techniques have been introduced. The Programme of Professional Calibration (PPC) was described in an 8-hour lecture series by PhD graduates in oral radiology and specialist in orthodontics [13]. Although this method had a positive influence on landmark identification, it required the involvement of professionals in the calibration process, hindering its implementation for all physicians in daily practice. The second method introduced the use of specialized software for the calibration process – which in this case was based on comparative analyses between the examiners and users [14]. Thus, this technique could be more broadly available, but was limited as only managing users could choose the landmarks for calibration. The technique allowed for the comparison of results with only pre-specified examiners, and the involvement of third-person manager users, who were responsible for information management, decreased the usability of this method. The last method was an online application designed for students to practice cephalometric tracings [15]. This technique was not directly related to landmark identification calibration, but provided

an opportunity for the comparison of detection skills on anatomical structures on cephalograms. However, computer-aided cephalometry has still not resolved the problem of random error, which is mainly the result of deviations in landmark identification [16]. Another attempt to eliminate this problem was the introduction of fully automatic analyses. Unfortunately, the accuracy of these methods remains poor (less than 2 mm), excluding them from use in clinical practice [17]. Hence, computer-aided methods are currently the most clinically efficient techniques for cephalometric analyses. The aforementioned problem of random error, especially as it relates to the reproducibility of landmark identification, has been the subject of numerous studies [4, 11]. However, to our knowledge, none of these previous studies has addressed the possible influence of landmark errors on cephalometric angular measurements. This is an important issue, as the size of any resulting angular changes determines acceptable versus insignificant landmark inaccuracies. Thus, the aims of this study were: to identify the possible influence of linear landmark deviations on the X and Y axes on angular measurements, and to propose and present an individual cephalometric calibration to overcome the drawbacks of the aforementioned calibration techniques.

Material and Methods

The definitions of all landmarks, lines and angles used in this study are presented in Table 1.

Measurements of Angular Changes

For the purpose of this experiment, we created a reference cephalometric template in the free-ware GeoGebra software (International GeoGebra Institute, Linz, Austria) (Fig. 1). Based on the template, the ideal values of the “S”, “N”, “ANS”, “A”, “B”, “Go”, “tgo”, “Pm”, and “Gn” landmark locations were modified for 0.5 mm, 1 mm, 2 mm, 3 mm and 4 mm in each direction on the X and Y axes. Subsequently, angular changes were noted, and the template was undone and reset to the initial position.

Individual Calibration

Two computer applications are required to perform the calibration process described below. The first is ImageJ, which can be freely accessed from: <http://imagej.nih.gov/ij/> (Wayne Rasband, National Institutes of Health, USA). The second is any

spreadsheet application. After application installation, three digital cephalograms must be prepared. The calibration process consists of four steps.

Setting the Scale

To start the calibration process, we open the first digital cephalogram in ImageJ by choosing the “Open” command from the “File” dropdown menu. Clicking the “+” key/button allows us to zoom on the ruler on the cephalostat. The “Straight” tool from the graphic user interface (GUI) can measure a distance corresponding to 10 mm on the cephalostat ruler. Next, we need to choose the “Set scale” command from the “Analyze” dropdown menu and enter the measured value of 10 mm in the “Known distance” dialog box. This allows us to set the proper scale of our cephalogram.

Selecting the Landmarks

Before starting landmark selection, we left-click on the “Point” tool from the GUI and check if “Mark width” is set to 10 px and that the “Auto-measure” option is marked. Next, we unmark all options in the “Set measurements” section in the “Analyze” dropdown menu. At this step, we can start selecting the cephalometric landmarks using the “Point” tool. It is important to select landmarks in the same order in each repeated procedure. After all the landmarks are selected, we use the “Edit” dropdown menu to choose the “Options” and “Input/Output...” commands. This causes a new window to appear, in which we must unmark the “Copy column head” and “Copy row number” options.

Transferring the Results

We need to select all the values from the “Results” window and copy them to the “cephalometry 1” column in the calibration template (Supplementary material 1).

Then, we repeat these three steps for each of the three prepared cephalograms. This procedure should be performed three times within a one-week interval by copying the values from the “Results” window to the trial 2 and trial 3 columns.

Reading Results

The results are presented according to the accuracy classification described in Olszewski et al. [18]. The results displayed on white backgrounds have an error < 1 mm, while those displayed on green, yellow, or red backgrounds have errors between 1–2 mm, 2–3 mm and > 3 mm, respectively.

The calibration process is presented in Figure 2.

Results

The differences in the angular measurements according to deviations in the landmark locations are presented in Table 2. For all angular measurements, a landmark selection error ≥ 2 mm resulted in a change of more than 1 degree. For the SNA angle, a change greater than 1 degree appeared only when the “S” landmark was shifted vertically, the “A” landmark was shifted horizontally and the “N” landmark was shifted in both directions. Similarly, the SNB angle value was greater than 1 degree when the “S” landmark was shifted vertically, the “B” landmark was shifted horizontally, and the “N” landmark was shifted in both directions. For the SNA angle, a change of more than 1 degree was only observed when the “S” landmark was shifted vertically, the “A” landmark was shifted horizontally, and the “N” landmark was shifted in both directions. The ANB angle was invariable for the “N” landmark deviation, but a horizontal change of ≥ 2 mm in the position of the “A” and “B” landmarks resulted in angular changes. For an extreme landmark involved in the NL-NSL, ML-NSL and ML-NL angles, any vertical dislocation resulted in angular changes in the listed angles. Differences in the horizontal position did not affect any of the three aforementioned angles.

Discussion

Errors in cephalometry can be divided into random errors and systematic errors [17]. Systematic errors arise from the lack of compensation of cephalogram magnification, and can be minimized using digital radiography. Random errors result from either landmark position deviations or measurement inaccuracies. In the era of digital cephalometry, in which ruler-based measurements have been excluded from everyday practice, linear and angular inaccuracies should be considered the results of improper landmark positions. Our study shows the potential influence of landmark deviations on angular measurements (Table 2).

It should be noted that when the distance between the edge landmarks of the angle and central landmark increased, the influence of inaccuracies in the landmark selection decreased. Only unidirectional landmark dislocations affected the specific angular measurements. Angles that were horizontally orientated (NL-NSL, ML-NSL, ML-NL) were affected by vertical deviations in the landmark locations. Similarly, for vertically oriented angles (ANB), only horizontal landmark displacements had any evident influence on the angle values. Nevertheless, wide angles such as SNA and SNB could be bilaterally susceptible to shifts due to either

Fig. 1. 1) diagram showing the landmarks used for measurement; 2) pattern cephalometric analysis with the GeoGebra software. The exact linear and angular dimensions are presented in the column

Fig. 2. Diagram showing the individual calibration procedures. 1) opening the cephalometric image; 2) zooming in on and selecting the straight line joining the distance of 10 mm on cephalostat ruler; 3) setting the magnification scale by typing the known previously measured distance (10 mm); (4) selecting the landmark using the "Point" tool; 5) copying the measured values into the calibration template; 6) calibrating the results according to the categories described by Olaszewski et al. [18]: the white background represents differences < 1 mm, the green background represents differences between 1–2 mm, the yellow background represents differences between 2–3 mm, and the red background represents differences > 3 mm

Table 1. Definitions of all landmarks, lines and angles

Abbreviation	Type	Definition
A	landmark	the deepest point on the anterior contour of the maxillary alveolar process
B	landmark	the deepest point on the anterior contour of the mandibular alveolar process
N	landmark	the most anterior lying point on the nasofrontal suture
S	landmark	the center of the bony crypt, sella turcica
ANS	landmark	the most anterior point lying on the anterior nasal spine
Gn	landmark	the most inferior point on the mandibular symphysis
Go	landmark	the intersection of the ml line and the ramus line
Pm	landmark	the intersection of the posterior contour of the maxilla with the contour of the hard and soft palate
Ar	landmark	the intersection of the external contour of the cranial base with the dorsal contour of the neck of the mandible (collum mandibulae)
ANB	angle	angle between A, N and B landmarks
SNA	angle	angle between S, N and A landmarks
SNB	angle	angle between S, N and B landmarks
ML-NSL	angle	angle between ML and NSL lines
NL-NSL	angle	angle between NL and NSL lines
ML-NL	angle	angle between ML and NL lines
NSL	line	connection between landmark S and landmark N. Represents the cranial base
NL	line	connection between landmark Pm and landmark ANS. Used as the reference line of the maxillary base
ML	line	tangent from landmark Gn to the inferior border of the angle of the mandible. Used as the reference line of the body of the mandible
Ramus Line	line	tangent from landmark AR to the most posterior point of the mandibular angle concavity

horizontal or vertical displacements. This result suggests that, in most cases, only unidirectional corrections for specific landmarks would be necessary to obtain reproducible measurements. One solution to this problem would be the use of tentative landmark definitions. Fuyamada et al. [19] showed that using separate definitions of landmark locations on each axis significantly improved the selection accuracy. This method could also reduce the time required to implement any necessary corrections.

The second part of this study consisted of the presentation of individual cephalometric calibrations to increase the accuracy of the selected landmarks. This may be of particular importance when planning orthognathic surgery, where any linear or angular error may be enlarged during surgical wafer fabrication and further surgery. Follow-up measurements also require reproducible landmark selection to accurately assess treatment outcomes. Finally, the introduction of cephalometric calibration during the education process may increase awareness among students that cephalometry results are highly dependent on performance precision. We proposed a calibration method that

allowed for the detection of landmark inaccuracies in the X and Y axes. This method was based on freely available software and does not require any third-party participation. Because cephalometric analyses are based on comparisons between current and planned tracings or between two measurements collected at different times of growth, one of the examinations is considered to be the reference template for the other. This process frees this method from the need for a reference template created by an expert in cephalometry and instead requires individual calibration between cooperating clinicians. Therefore, our templates allow the calculation of mean and maximum differences, as well as standard deviations between measurements performed by one or more physicians (Supplementary material 1). Inter- and intra-observer reliability could also be measured using the interclass correlation coefficient [20], although this measure is dimensionless, thus decreasing its clinical usefulness. The concept of the smallest detectable difference (SDD) was introduced to cephalometry by Damstra et al. [20]. As authors have stated, the SDD defines the 95% confidence limit of the method error. Later calculations estimat-

Table 2. Differences in angular measurements

SNA

	0.5 mm down	0.5 mm up	0.5 mm left	0.5 mm right	1 mm down	1 mm up	1 mm left	1 mm right	2 mm down	2 mm up	2 mm left	2 mm right	3 mm down	3 mm up	3 mm left	3 mm right	4 mm down	4 mm up	4 mm left	4 mm right
S	-0.44°	0.43°	0.08°	-0.08°	-0.87°	0.87°	0.15°	-0.16°	-1.73°	1.74°	0.3°	-0.33°	-2.58°	2.62°	0.45°	-0.5°	-3.43°	3.5°	0.59°	-0.67°
N	0.45°	-0.45°	0.36°	-0.08°	0.91°	-0.9°	0.72°	-0.72°	1.82°	-1.79°	1.43°	-1.45°	2.74°	-2.68°	2.14°	-2.19°	3.66°	-3.56°	2.84°	-2.93°
A	-0.02°	0.01°	-0.44°	0.44°	-0.03°	0.03°	-0.88°	1.32°	-0.07°	0.07°	-1.32°	2.2°	-0.1°	0.11°	-2.2°	2.63°	-0.23°	0.15°	-3.63°	3.51°

SNB

	0.5 mm down	0.5 mm up	0.5 mm left	0.5 mm right	1 mm down	1 mm up	1 mm left	1 mm right	2 mm down	2 mm up	2 mm left	2 mm right	3 mm down	3 mm up	3 mm left	3 mm right	4 mm down	4 mm up	4 mm left	4 mm right
S	-0.44°	0.43°	0.08°	-0.08°	-0.87°	0.87°	0.15°	-0.16°	-1.73°	1.74°	0.3°	-0.33°	-2.58°	2.62°	0.45°	-0.5°	-3.43°	3.5°	0.59°	-0.67°
N	0.43°	-0.44°	0.2°	-0.08°	0.86°	-0.88°	0.4°	-0.43°	1.74°	-1.74°	0.81°	-0.85°	2.62°	-2.6°	1.21°	-1.27°	3.51°	-3.45°	1.61°	-1.71°
B	0°	0.01°	-0.28°	0.29°	0°	0.01°	-0.57°	0.58°	0°	0.01°	-1.14°	1.15°	0°	0.01°	-1.72°	1.72°	0°	0.01°	-2.29°	2.29°

ANB

	0.5 mm down	0.5 mm up	0.5 mm left	0.5 mm right	1 mm down	1 mm up	1 mm left	1 mm right	2 mm down	2 mm up	2 mm left	2 mm right	3 mm down	3 mm up	3 mm left	3 mm right	4 mm down	4 mm up	4 mm left	4 mm right
A	-0.02°	0.02°	-0.44°	0.44°	-0.03°	0.03°	-0.88°	1.32°	-0.07°	0.07°	-1.32°	2.2°	-0.1°	0.11°	-2.2°	2.63°	-0.23°	0.15°	-3.63°	3.51°
N	0.03°	-0.01°	0.16°	0°	0.04°	-0.02°	0.32°	-0.3°	0.08°	-0.05°	0.62°	-0.61°	0.11°	-0.08°	0.92°	-0.91°	0.15°	-0.11°	1.23°	-1.22°
B	-0.01°	-0.01°	0.28°	-0.29°	0°	-0.01°	0.57°	-0.58°	0°	-0.01°	1.14°	-1.15°	0°	-0.01°	1.72°	-1.72°	-0.01°	-0.02°	2.29°	-2.29°

NL-NSL

	0.5 mm down	0.5 mm up	0.5 mm left	0.5 mm right	1 mm down	1 mm up	1 mm left	1 mm right	2 mm down	2 mm up	2 mm left	2 mm right	3 mm down	3 mm up	3 mm left	3 mm right	4 mm down	4 mm up	4 mm left	4 mm right
N	-0.4°	0.46°	0.11°	0.08°	-0.84°	0.9°	0.19°	-0.12°	-1.78°	1.75°	0.35°	-0.27°	-2.6°	2.61°	0.53°	-0.43°	-3.48°	3.46°	0.7°	-0.67°
S	0.44°	-0.43°	-0.08°	0.08°	0.87°	-0.87°	-0.15°	0.16°	1.73°	-1.74°	-0.3°	0.33°	2.58°	-2.62°	-0.45°	0.5°	3.43°	-3.5°	-0.59°	0.67°
ANS	0.41°	-0.4°	0.07°	0.06°	0.81°	-0.8°	0.14°	-0.13°	1.61°	-1.62°	0.29°	-0.27°	2.4°	-2.43°	0.44°	-0.39°	3.2°	-3.25°	0.75°	-0.64°
Pm	-0.36°	0.45°	-0.02°	0.12°	-0.76°	0.85°	-0.09°	0.19°	-1.57°	1.65°	-0.22°	0.33°	-2.39°	2.45°	-0.35°	0.48°	-3.21°	3.24°	-0.48°	0.64°

Table 2. Differences in angular measurements

ML-NSL

	0.5 mm down	0.5 mm up	0.5 mm left	0.5 mm right	1 mm down	1 mm up	1 mm left	1 mm right	2 mm down	2 mm up	2 mm left	2 mm right	3 mm down	3 mm up	3 mm left	3 mm right	4 mm down	4 mm up	4 mm left	4 mm right
N	-0.4°	0.46°	0.11°	0.08°	-0.84°	0.9°	0.19°	-0.12°	-1.78°	1.75°	0.35°	-0.27°	-2.6°	2.61°	0.53°	-0.43°	-3.48°	3.46°	0.7°	-0.67°
S	0.44°	-0.43°	-0.08°	0.08°	0.87°	-0.87°	-0.15°	0.16°	1.73°	-1.74°	-0.3°	0.33°	2.58°	-2.62°	-0.45°	0.5°	3.43°	-3.5°	-0.59°	0.67°
Gn	0.42°	-0.42°	0.13°	-0.13°	0.84°	-0.84°	0.27°	-0.27°	1.66°	-1.7°	0.55°	-0.53°	2.48°	-2.55°	0.84°	-0.77°	3.29°	-3.42°	1.14°	-1.02°
tgo	-0.42°	0.42°	-0.13°	0.13°	-0.84°	0.84°	-0.27°	0.27°	-1.7°	1.66°	-0.53°	0.55°	-2.55°	2.48°	-0.77°	0.84°	-3.42°	3.29°	-1.02°	1.14°

ML-NL

	0.5 mm down	0.5 mm up	0.5 mm left	0.5 mm right	1 mm down	1 mm up	1 mm left	1 mm right	2 mm down	2 mm up	2 mm left	2 mm right	3 mm down	3 mm up	3 mm left	3 mm right	4 mm down	4 mm up	4 mm left	4 mm right
ANS	-0.41°	0.4°	-0.07°	0.06°	-0.81°	0.8°	-0.14°	0.13°	-1.61°	1.62°	-0.29°	0.27°	-2.4°	2.43°	-0.44°	0.39°	-3.2°	3.25°	-0.75°	0.64°
Pm	0.36°	0.45°	0.02°	-0.12°	0.76°	-0.85°	0.09°	-0.19°	1.57°	-1.65°	0.22°	-0.33°	2.39°	-2.45°	0.35°	-0.48°	3.21°	-3.24°	0.48°	-0.64°
Gn	0.42°	-0.42°	0.13°	-0.13°	0.84°	-0.84°	0.27°	-0.27°	1.66°	-1.7°	0.55°	-0.53°	2.48°	-2.55°	0.84°	-0.77°	3.29°	-3.42°	1.14°	-1.02°
tgo	-0.42°	0.42°	-0.13°	0.13°	-0.84°	0.84°	-0.27°	0.27°	-1.7°	1.66°	-0.53°	0.55°	-2.55°	2.48°	-0.77°	0.84°	-3.42°	3.29°	-1.02°	1.14°

Angular differences greater than 1 degree are shown in bold.

Supplementary materials. Template for the intra- and inter-observer calibration

	Trial 1						Trial 2						Trial 3					
	cephalogram 1			cephalogram 2			cephalogram 3			cephalogram 1			cephalogram 2			cephalogram 3		
	X axis	Y axis		X axis	Y axis		X axis	Y axis		X axis	Y axis		X axis	Y axis		X axis	Y axis	
1. Point	0	0		0	0		0	0		0	0		0	0		0	0	
2. Point	0	0		0	0		0	0		0	0		0	0		0	0	
3. Point	0	0		0	0		0	0		0	0		0	0		0	0	
4. Point	0	0		0	0		0	0		0	0		0	0		0	0	
5. Point	0	0		0	0		0	0		0	0		0	0		0	0	
6. Point	0	0		0	0		0	0		0	0		0	0		0	0	
7. Point	0	0		0	0		0	0		0	0		0	0		0	0	
8. Point	0	0		0	0		0	0		0	0		0	0		0	0	
9. Point	0	0		0	0		0	0		0	0		0	0		0	0	
10. Point	0	0		0	0		0	0		0	0		0	0		0	0	
11. Point	0	0		0	0		0	0		0	0		0	0		0	0	
12. Point	0	0		0	0		0	0		0	0		0	0		0	0	
13. Point	0	0		0	0		0	0		0	0		0	0		0	0	
14. Point	0	0		0	0		0	0		0	0		0	0		0	0	
15. Point	0	0		0	0		0	0		0	0		0	0		0	0	

	Results					
	mean difference (mm)			standard deviation (mm)		
	X axis	Y axis		X axis	Y axis	maximal difference (mm)
1. Point	0	0		0,00	0,00	X axis 0 Y axis 0
2. Point	0	0		0,00	0,00	0 0
3. Point	0	0		0,00	0,00	0 0
4. Point	0	0		0,00	0,00	0 0
5. Point	0	0		0,00	0,00	0 0
6. Point	0	0		0,00	0,00	0 0
7. Point	0	0		0,00	0,00	0 0
8. Point	0	0		0,00	0,00	0 0
9. Point	0	0		0,00	0,00	0 0
10. Point	0	0		0,00	0,00	0 0
11. Point	0	0		0,00	0,00	0 0
12. Point	0	0		0,00	0,00	0 0
13. Point	0	0		0,00	0,00	0 0
14. Point	0	0		0,00	0,00	0 0
15. Point	0	0		0,00	0,00	0 0

ed that the smallest detectable inter-observer differences for SNA, SNB and ANB for above 2 mm were 2.12, 2.31 and 2.57, respectively. This could be of importance as long as the norm for SNA, SNB, and ANB are within 2 degrees. However, more accurate landmark identification provided by cephalometric calibration may improve the SDD to allow for more precise measurements. The presented calibration and influence of landmark dislocation refers to the simple deviation of one axis at a time, whereas in everyday practice, any inaccuracies occur in all axes simultaneously. This may be of minor importance for landmarks used only for measurements in one (horizontal or vertical) orientation, but it is crucial for landmarks used for several measurements at the same time.

Conclusions

Landmark deviations of ≥ 2 mm result in changes in the angular measurements of 1 degree or more. Depending on the landmark dislocation direction (horizontal or vertical), the angular measurements can be affected in either a minor or major way. Individual calibration allows for the detection of inaccuracies in the X and Y axes. Detailed analysis of the calibration results makes possible the correction of the selected errors, which could result in more accurate measurements during cephalometric analysis and the detection of more subtle changes.

References

- [1] XU Y., YANG C., SCHREUDER W.H., SHI J., SHI B., ZHENG Q., WANG Y.: Cephalometric analysis of craniofacial morphology and growth in unrepaired isolated cleft palate patients. *J. Craniomaxillofac. Surg.* 2014, 42, 1853–1860.
- [2] CONTARDO L., CESCHI M., CASTALDO A., DENOTTI G., DI LENARDA R.: Differences in skeletal class II diagnosis using various cephalometric analyses. *J. Clin. Orthod.* 2008, 42, 389–392.
- [3] PAE E.K., MCKENNA G.A., SHEEHAN T.J., GARCIA R., KUHMBERG A., NANDA R.: Role of lateral cephalograms in assessing severity and difficulty of orthodontic cases. *Am. J. Orthod. Dentofacial. Orthop.* 2001, 120, 254–262.
- [4] DURÃO A.R., PITTAYAPAT P., ROCKENBACH M.I., OLSZEWSKI R., NG S., FERREIRA A.P., JACOBS R.: Validity of 2D lateral cephalometry in orthodontics: A systematic review. *Prog. Orthod.* 2013, 14, 31.
- [5] NIJKAMP P.G., HABETS L.L., AARTMAN I.H., ZENTNER A.: The influence of cephalometrics on orthodontic treatment planning. *Eur. J. Orthod.* 2008, 30, 630–635.
- [6] DURÃO A.R., ALQERBAN A., FERREIRA A.P., JACOBS R.: Influence of lateral cephalometric radiography in orthodontic diagnosis and treatment planning. *Angle Orthod.* 2015, 85, 206–210.
- [7] KEIM R.G., GOTTLIEB E.L., NELSON A.H., VOGELS D.S.: 2002 JCO study of orthodontic diagnosis and treatment procedures. Part 1. Results and trends. *J. Clin. Orthod.* 2002, 36, 553–568.
- [8] BROADBENT B.: A new X-ray technique and its application to orthodontia. *Angle Orthod.* 1931, 1, 45–66.
- [9] DELAIRE J., SCHENDEL S.A., TULASNE J.F.: An architectural and structural craniofacial analysis: A new lateral cephalometric analysis. *Oral Surg. Oral Med. Oral Pathol.* 1981, 52, 226–238.
- [10] DOWNS W.B.: Variations in facial relationships; their significance in treatment and prognosis. *Am. J. Orthod.* 1948, 34, 812–840.
- [11] McWILLIAM J.S.: Evaluation and calibration of X-Y-coordinatographs used in cephalometric analysis. *Scand. J. Dent. Res.* 1980, 88, 496–504.
- [12] UYSAL T., BAYSAL A., YAGCI A.: Evaluation of speed, repeatability, and reproducibility of digital radiography with manual versus computer-assisted cephalometric analyses. *Eur. J. Orthod.* 2009, 31, 523–528.
- [13] DELAMARE E.L., LIEDEKE G.S., VIZZOTTO M.B., DA SILVEIRA H.L., RIBEIRO J.L., SILVEIRA H.E.: Influence of a programme of professional calibration in the variability of landmark identification using cone beam computed tomography-synthesized and conventional radiographic cephalograms. *Dentomaxillofac. Radiol.* 2010, 39, 414–423.
- [14] SILVEIRA H.L., SILVEIRA H.E., DALLA-BONA R.R., ABDALA D.D., BERTOLDI R.F., VON WANGENHEIM A.: Software system for calibrating examiners in cephalometric point identification. *Am. J. Orthod. Dentofacial. Orthop.* 2009, 135, 400–405.
- [15] LEONARDI R., GIORDANO D., CALTABIANO M.: Interactive online program to improve cephalometric tracing skills. *Am. J. Orthod. Dentofacial Orthop.* 2004, 126, 256–258.
- [16] ALBARAKATI S.F., KULA K.S., GHONEIMA A.A.: The reliability and reproducibility of cephalometric measurements: A comparison of conventional and digital methods. *Dentomaxillofac. Radiol.* 2012, 41, 11–17.
- [17] LEONARDI R., GIORDANO D., MAIORANA F., SPAMPINATO C.: Automatic cephalometric analysis. *Angle Orthod.* 2008, 78, 145–151.
- [18] OLSZEWSKI R., FRISON L., WISNIEWSKI M., DENIS J.M., VYNCKIER S., COSNARD G., ZECH F., REYCHLER H.: Reproducibility of three-dimensional cephalometric landmarks in cone-beam and low-dose computed tomography. *Clin. Oral Investig.* 2013, 17, 285–292.
- [19] FUYAMADA M., NAWA H., SHIBATA M., YOSHIDA K., KISE Y., KATSUMATA A., ARIJI E., GOTO S.: Reproducibility of landmark identification in the jaw and teeth on 3-dimensional cone-beam computed tomography images. *Angle Orthod.* 2011, 81, 843–849.
- [20] DAMSTRA J., HUDDLESTON SLATER J.J., FOURIE Z., REN Y.: Reliability and the smallest detectable differences of lateral cephalometric measurements. *Am. J. Orthod. Dentofacial Orthop.* 2010, 138, 546.e1–548.e8.

Address for correspondence:

Tomasz Smehtała
Maxillofacial Surgery Department
Pomeranian Medical University
Unii lubelskiej 1
71-252 Szczecin
Poland
Tel.: 91 466 11 17
E-mail: smektala.t@gmail.com

Conflict of interest: None declared

Received: 6.02.2016

Revised: 24.03.2016

Accepted: 1.04.2016