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ORIGINAL ARTICLE

Skeletal-versus soft-tissue-based cephalometric analyses: is the correlation reproducible?

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ABSTRACT

Objectives: Dentofacial deformities can be analyzed by skeletal and soft tissue cephalometric analysis (CA). The aim was to evaluate the difference in reproducibility between both methods.

Materials and methods: Lateral cephalograms of 112 patients (65 females and 47 males, 27.7 ± 9.0 years) were oriented in natural head position (NHP) and digitized. The distances of skeletal (SNA, SNB, SnPog) and soft tissue (*A′*, *B′* and Pog′) landmarks relative to the respective norm values and the angles between the Nasion Sella line (NSL) and Frankfurt horizontal (FH) to NHP were measured for statistical evaluation and compared with respective data of an adult control group (CG) with class I occlusion and harmonic facial balance.

Results: The mean differences (mm ± SD) of skeletal and soft tissue landmarks were −2.4 ± 4.4 (*A*), −7.0 ± 9.3 (*B*), −6.3 ± 11.2 (Pog), −0.9 ± 1.8 (*A′*), −4.7 ± 6.2 (*B′*), and −6.1 ± 7.8 (Pog′), respectively. Pearsons's correlation (r) between the measurements of SNA/*A′*, SNB/*B′* and SNPog/Pog′ were $r = .158$ ($p = .092$), $r = .662$ ($p < .001$) and $r = .655$ ($p < .001$), respectively. The mean (±SD) angles between NSL and FH to NHP were −9.8° ± 5 and 0.0° ± 3.9, respectively.

Conclusion: Variability of cranial-based measurements could give a possible explanation for the high variation and the low reproducibility of skeletal cephalometric analysis with soft tissue measurements. Soft-tissue cephalometric analysis would probably improve facial analysis and treatment planning.

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Introduction

Cephalometric analysis (CA) of dentofacial deformities is an important part of the preparation for orthodontic and orthognathic treatment [1]. Numerous variations of CA have been developed in an attempt to define the direction of treatment more objectively [2,3]. Two methods can be distinguished: skeletal and soft tissue CA. Skeletal cephalometric analysis (SKCA) is based on cranial base structures, e.g. the Nasion Sella line (NSL), and emphasis is placed on measurements of skeletal and dental structures within the head films (Figures 1 and 2). Measurements of distances, angles, or ratios between anatomical landmarks (e.g. NSL-A) have been used to objectify the amount of deviation proportionately to standard values [1,3]. Several authors have questioned the validity of these measurements because of their variability and therefore low reliability [4,5]. A variation of the corresponding skeletal structures by up to 20° is described if the cranial base is employed as a reference [6]. Use of various intracranial orientation planes can sometimes lead to completely different findings in the same patient [4,6]. In cases of the obvious deviation of skull base structures, lateral cephalograms need to be re-oriented relative to a horizontal reference plane, and angular and linear measurements from skull base structures to landmarks have to be adapted to this position [7,8]. As a horizontal reference plane, the Frankfurt horizontal (FH) is frequently used for head orientation in CA [9]. However, various authors have questioned the validity of this line, because of the large variation to natural head posture [9–12].

Soft tissue cephalometric analysis (STCA) relies on natural head posture, and the vertical and horizontal positions of soft tissue landmarks identified on cephalograms or photographs are recorded relative to the patient's head position [5,10]. To define a reference plane, the natural head position (NHP) is frequently used and is defined as the head position when the visual axis of a standing patient is exactly horizontal (Figure 3(A)) [4,13,14]. A line perpendicular to the horizontal in NHP, the true vertical line (TVL), is used as a reference for the measurements of soft and hard tissue landmarks identified on cephalograms or photographs (Figures 1 and 2) [6]. The vertical and horizontal positions of these landmarks are recorded relative to the patient's NHP or TVL [15,16]. Although the use of intracranial reference planes for the assessment of the anterior–posterior skeletal relationship has

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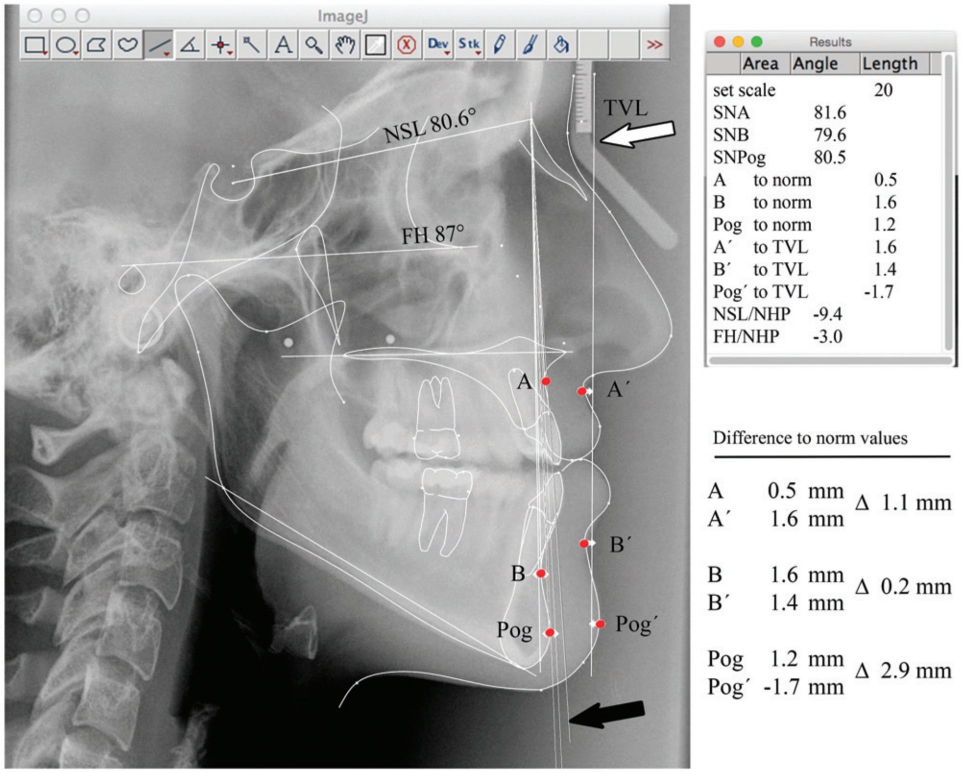

Figure 1. Screenshot for measuring distances (in mm) and angles (°) on a lateral cephalogram using ImageJ software: NSL and FH with the respective angles (°) relative to TVL (white arrow). Linear measurements of skeletal landmarks *A*, *B* and Pog to the respective norm lines (SNA, SNB, SNPog) and of soft tissue landmarks *A*′, *B*′ and Pog′ to the TVL. The black arrow indicates the respective norm lines for SNA (82°), SNB (80.5°) and SNPog (81°).

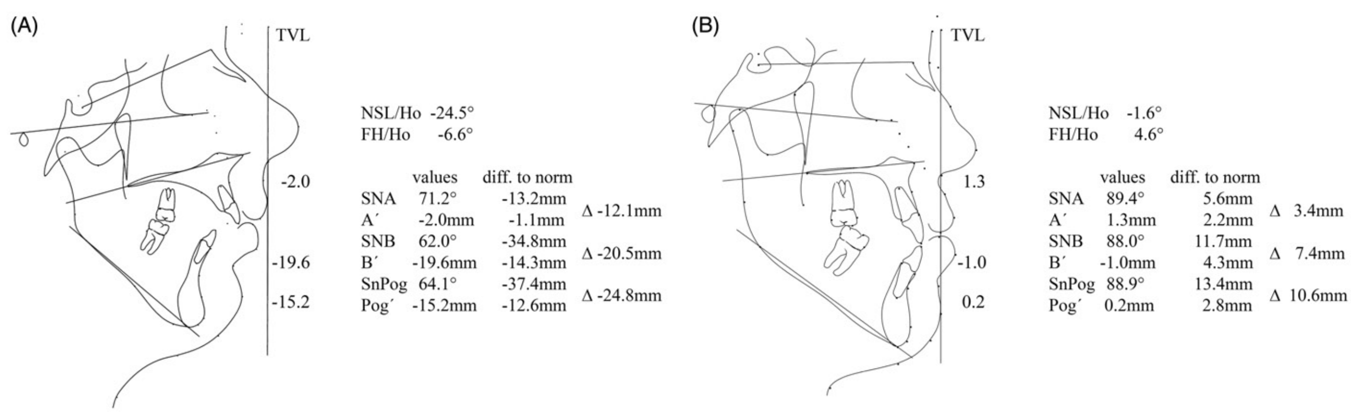

Figure 2. TVL, NSL and FH are displayed with the respective angles relative to the true horizontal line (perpendicular to TVL). Measurements of soft tissue landmarks (*A*′, *B*′, Pog′) are displayed at the TVL. (A) A patient showing dental class II occlusion. (B) A patient showing dental class III occlusion.

for some time been known to be inherently unreliable, they are still widely employed by orthodontists and surgeons for CA and treatment planning [5]. As a consequence, and in expectation of a weak association, the aim of the study was to assess the difference between skeletal (cranial base) and soft tissue (head posture) cephalometric measurements.

Material and method

Subjects

The collective comprised of 112 Caucasian individuals (47 males, 42.0%, and 65 females, 58.0%) with a mean age of 27.7 ± 9.0 years (range 14–63 years) (ethical approval number EK-2-2014/0016 and written consent by all subjects) being consecutively treated for surgical correction of skeletal-related malocclusion at the Department of Oral and Maxillofacial Surgery at the Academic teaching hospital Feldkirch, Austria between 2012 and 2014 (skeletal relationships: 85 Class II (75.9%) and 27 Class III (24.1%)). All patients had received previous orthodontic treatment for alignment and decompensation of the teeth.

Head orientation, radiography and photography

In order to enable reliable and reproducible superimposition of the cephalogram and lateral photography of the patient's face a standard protocol was used (Figure 3(A–C)) [17]. All preoperative cephalograms were routinely performed in NHP

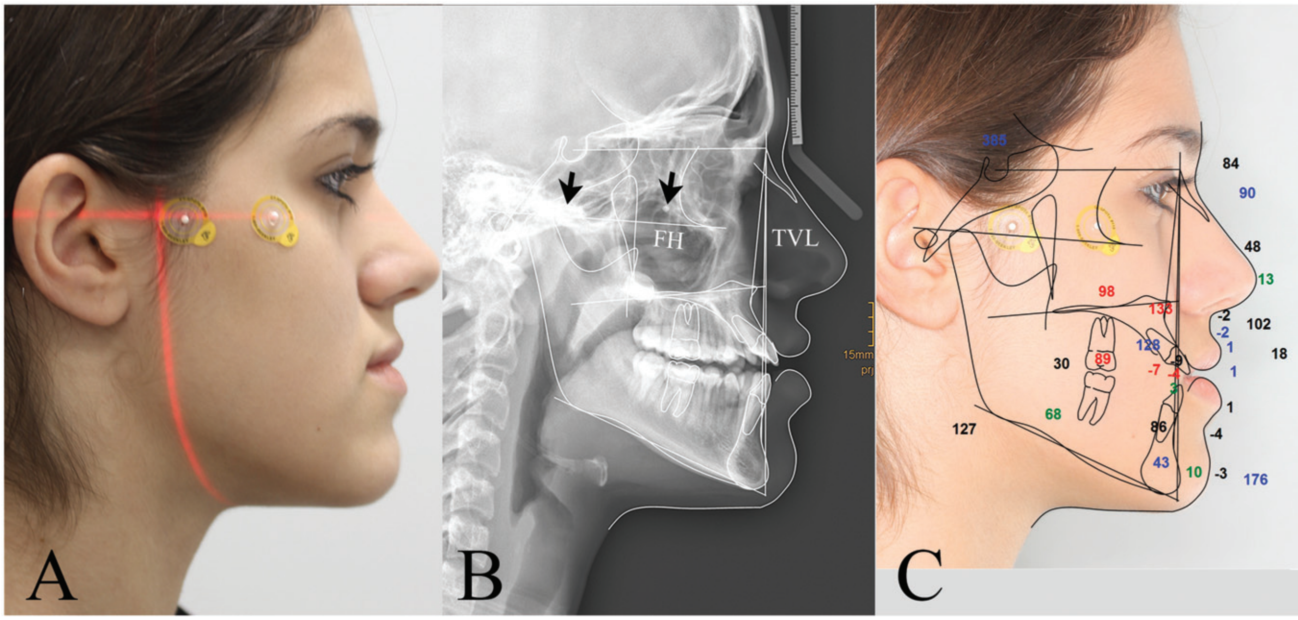

Figure 3. Presentation of the method to superimpose lateral head photo and the lateral cephalogram. Note the laser light used for projection of a horizontal line onto the patient's lateral face. A: Lateral head photo. Radiopaque markers are levelled on to the laser light projection orientated in NHP according to Arnett and McLaughlin [17], B: Lateral cephalogram with the same orientation (arrows indicate the corresponding radiopaque markers), true vertical line (TVL) and Frankfurt horizontal (FH) are displayed. C: Presentation of the method to superimpose lateral head photo and the lateral cephalogram.

in an upright position, tilting their head up and down three times until they felt that they were relaxed, and to adopt the head to their casual balanced position for viewing the horizon. Compensated positions were corrected by one experienced investigator (O.P). A laser light (Bosch PCL 1, Robert Bosch GmbH, Leinfelden–Echterdingen, Germany) mounted on a tripod (Manfrotto 322RC2, Cassola, Italy) was used to project a horizontal line onto the patient's lateral face (Figure 3(B)). The vertical position of the tripod was changed to accommodate the individual's height. When the patient's NHP was attained, two radiopaque markers (diameter 1.0 mm) were taped onto the face (Figure 3(A)). A lateral photograph was taken using a 8.2-megapixel semi-professional digital single-lens reflex camera (Canon D20, Canon Corp, USA), a 105 mm macro lens (Tamron SP 90 mm F/2.8, macro 1:1, AF), and a Canon speed light (Macroring lite MR-14EX, Canon, USA). The camera was mounted vertically on the tripod, 150 cm laterally from the patient's face. A lateral cephalogram was taken in a standing position with the radiopaque markers being kept level horizontally with the condyles seated in the joint, in a relaxed lip position, and teeth in first tooth contact (Figure 3(B)).

Measurements

The images were saved as tiff-files and imported into imaging freeware (Image J, NIH, USA). The cephalograms were calibrated with the visible caliper by using the "set scale" tool of the program and were oriented by means of the visible radiopaque markers. On each cephalogram, a millimeter caliper was displayed to calibrate the images. The TVL was placed through the subnasale and was perpendicular to the horizontal plane as described in the literature [5]. Eleven skeletal and soft tissue landmarks (sella, nasion, porion, orbitale, subnasale, *A*, *B*, Pog, *A*′, *B*′, Pog′) were digitized and three lines (NSL, FH and TVL through subnasale) were traced (Figure 1). A series of 15 cephalograms were randomly selected and three repeated measurements (SNA, SNB, SNPog, *A*′, *B*′, Pog′) were performed at three different time points by one investigator to calculate the intra-observer error (Dahlberg error and intraclass correlation). For soft tissue measurements the definition of the landmark subnasale and the orientation of TVL were included (Figure 4(A,B)).

The angles between NSL and FH (porion–orbitale) to the horizontal (perpendicular to TVL) were measured. In cases of the counter-clockwise rotation of NSL or FH relative to the horizontal, the values were negative. In order to compare angles of cranial base measurements (e.g. SNA in degrees) with metric measurements of soft tissue landmarks (e.g. *A*′ to TVL in mm), three angles through the nasion with the norm values 82°, 80.5° (SNB), and 81° (SNPog) were traced for later metric measurements. Horizontal lines were traced through the skeletal points *A*, *B* and Pog and through the soft tissue points (*A*′, *B*′ and Pog′). The distances from these points to the corresponding lines (e.g. landmark *A* to the line SNA-82° and landmark *A*′ to TVL) were measured and saved (Figures 1 and 2). All measurements were transferred to Excel 7.0 (Microsoft Corp., CA, USA) for later analysis. The differences between the measured distances of the soft tissue landmarks (e.g. *A*′ to TVL) and the respective norm values were calculated using the gender norm values for Caucasians (Table 1) [17]. The latter data base served as underlying control group (CG) consisting of 46 adult Caucasian (20 males, 26 female) with untreated class I occlusion and facially balanced

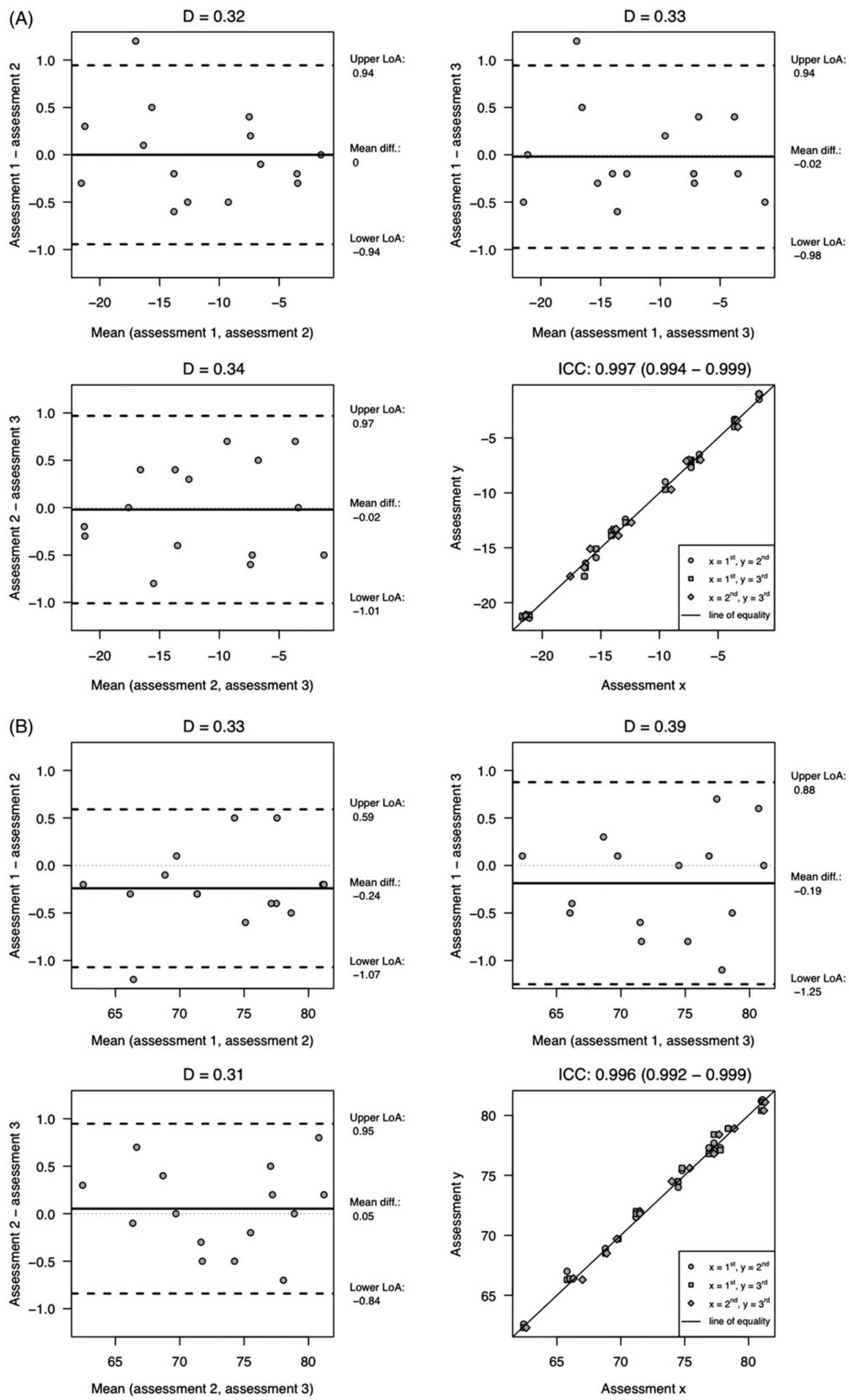

Figure 4. A: B-Point, B: SNB. Based on a series of 15 cephalograms that were randomly selected and three repeated measurements (SNA, SNB, SNPog, *A′*, *B′*, Pog′) were performed at three different time points by one investigator to calculate the intra-observer error Dahlberg error: (D) and intraclass correlation (ICC): (C). Exemplary representation of Bland–Altman plots for comparison of different measurements (1 vs. 2, 1 vs. 3, 2 vs. 3). The mean difference between the measurements and the "Limits of Agreement" are shown.

proportions. This CG is regarded as ideally proportioned collective. The soft tissue cephalometric analysis was performed in NHP with seated condyles and rested lips. Clinical facial examination was performed according to Arnett and Bergman [5,10] with special emphasis on midface structures in terms of exact indication of maxillary *A*/*P* position.

Statistical analysis

All data were transferred and analyzed using SPSS (release 18.5) for Windows statistical software package (SPSS, Chicago, IL, USA). Descriptive statistics with mean, standard deviation and maximum and minimum for each variable were calculated. The coefficient of determination (r^2) was calculated in order to determine certainty in making predictions from the respective method of measuring the reference points.

To calculate the magnitude of intra-observer random errors Dahlberg's formula and intraclass correlation (ICC) were performed [18,19]. For each variable (SNA, SNB, SNPog, *A*′, *B*′, Pog′) the Bland–Altman method has been applied to assess if repeated measurements series can be used interchangeably or not (1 vs. 2, 1 vs. 3, 2 vs. 3) [18,20] (Figure 4(A,B)). ICC with 95% confidence interval was calculated using the R-packet "ICC" and was based on the variance components of an ANOVA. Significance was established at the level of $p < .05$.

Results

Data for means, standard deviations, and ranges for skeletal (SNA, SNB and SNPog) and soft tissue variables (*A*′, *B*′ and Pog′) are presented in Table 2. The Dahlberg's errors in angular measurements (SNA, SNB and SNPog) were between 0.31 and 0.58 mm and in linear measurements (*A*′, *B*′ and Pog′ relative to the TVL) between 0.31 and 0.58°. ICC calculation revealed 0.913–0.997 and 0.980–0.997, respectively (Figure 5(A,B)). This demonstrates a high reproducibility respective minimal measurement error of the tracings in this study. The mean (±SD) differences (in mm) for SNA, SNB and SNPog to the respective norm values were −2.4 ± 4.4, −7.0 ± 9.3 and −6.3 ± 11.2, respectively. The mean (±SD) differences (in mm) for *A*′, *B*′ and Pog′ to the respective CG data were −.9 ± 1.8, −4.7 ± 6.2, and −6.1 ± 7.8, respectively (Table 3). In the CG mandibular projection like B′-TVL and Pog′-TVL were calculated with −5.3 ± 1.5/−7.1 ± 1.6 (female/male) and −2.6 ± 1.9/−3.5 ± 1.8.

Pearsons's correlation (*r*) and the coefficient of determination (r^2), were for the linear variable SNA/*A*′ $r = .158$ ($r^2 = .25$) and for SNB/*B*′ $r = .662$ ($r^2 = .438$) (Figure 5(A,B)). For SNPog/Pog′ $r = .655$ ($r^2 = .429$) was calculated (Figure 5(C)). The association of SNB/*B*′ and SnPog/Pog′ was statistically highly significant ($p < .001$), whereas correspondence between SNA and *A*′ was low ($p = .092$) (Figure 5(A–C)). The respective mean angles (±SD) formed between NSL and FH to NHP were −9.8° ± 5.0 (range −24.5–4.4) and 0.0° ± 3.9 (range −10.9–9.0).

Discussion

The question that arises is: if someone relies on only one method, is there a difference between both methods and if yes, is it clinically relevant? In order to compare angular (SKCA) with linear measurements (STCA), STCA relative to the respective norm values for both methods, together with a correlation analysis were performed. Interestingly, the correlation of the landmarks SNA/*A*′ was low, whereas that of SNB/*B*′ and SNPog/Pog′ was moderate (Figure 5(A–C)). In terms of geometric considerations (distance to the pivot point of head rotation), cephalometric measurements based

Table 1. Norm values for soft tissue landmarks relative to the TVL (in mm, through subnasale).

Soft tissue landmark	Males	Females
A′	−0.3 ± 1.0	−0.1 ± 1.0
B′	−7.1 ± 1.6	−5.3 ± 1.5
Pog′	−3.5 ± 1.8	−2.6 ± 1.9

For Caucasians different values are displayed for males and females according to Arnett and McLaughlin [17].
Data are presented as means ± standard deviation (SD).

Table 2. Measurements for skeletal (in °) (*A*, *B* and Pog) and soft tissue (in mm) (*A*′, *B*′ and Pog′) landmarks.

$n = 112$	SNA (°)	SNB (°)	SnPog (°)	*A*′ (mm)	*B*′ (mm)	Pog′ (mm)
Total	80.2 ± 4.1	76.1 ± 5.4	78.0 ± 5.6	−1.7 ± 1.8	−10.8 ± 6.2	−9.1 ± 7.8
Class II	80.2 ± 4.2	74.3 ± 4.2	76.2 ± 4.5	−1.6 ± 1.8	−12.6 ± 5.6	−11.0 ± 7.5
Class III	80.0 ± 4.5	81.8 ± 4.7	83.4 ± 5.2	−2.2 ± 1.7	−5.0 ± 3.9	−3.0 ± 5.0
Minimum	71.1	61.9	64.2	−6.1	−30.9	−35.2
Maximum	91.2	92.3	94.9	2.0	6.0	7.9

Table 3. Differences (in mm) in skeletal (*A*, *B* and Pog) and soft tissue (*A*′, *B*′ and Pog′) landmarks to the respective norm values.

	A	*A*′	*B*	*B*′	Pog	Pog′
Mean ± SD	−2.4 ± 4.4	−0.9 ± 1.8	−7.0 ± 9.3*	−4.7 ± 6.2*	−6.3 ± 11.2*	−6.1 ± 7.8*
minimum	−6.1	−5.4	−30.9	−23.8	−35.2	−31.7
maximum	2.0	2.7	6.0	13.1	8.0	11.5

*Statistically significant relationship of SNB/*B*′ and SNPog/Pog′ ($p < .001$).

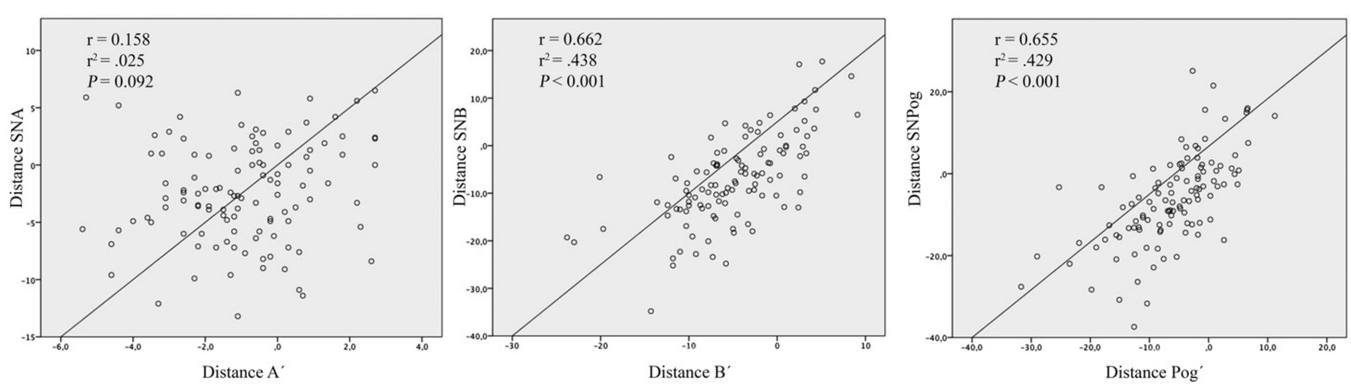

Figure 5. Scatter plot: correlation between the SNA/*A*′ (A, left), SNB/*B*′ (B, center) and SNPog/Pog′ (C, right). Correlation coefficient (*r*) and coefficient of determination (r^2) are shown for each pair of variables. The relationship of SNB/*B*′ and SNPog/Pog′ was statistically significant ($p < .001$).

on a vertical line to assess sagittal jaw position should be relatively precise in the maxilla but can be less accurate in the area of the mandible and the chin. Although the sagittal impact of rotating the head up and down, thereby changing head inclination in relation to the vertical, is much larger in the anterior part of the mandible than in the maxilla, this has not been revealed by our results. The low correlation of the SNA/*A′* points can be explained by insufficient compensation of the landmark subnasale in cases of midface deficiency. In our study, the *A/P* positioning of the TVL was drawn through the subnasale as described in the literature [5]. In such a clinical situation, this point has to be moved forward depending on the amount of midface retrusion to achieve a suitable position relative to the face. Midface retrusion is defined by a long nose, deficient nasal base, poor incisor upper lip support, upright upper lip, and/or thick upper lip and has to be identified prior to treatment planning [10,21]. As a consequence, careful clinical analysis of the patient′s midface is necessary to avoid misleading information attributable to a malposition of the TVL. A malposition or inadequate compensation of the TVL might explain the low correlation of SNA/*A′*, as obvious in our results. To overcome the problem of an inadequate position of the landmark subnasale, the TVL can be placed through a different reference structure, such as the glabella [22]. Optimal anteroposterior position of the maxilla is achieved when the decompensated maxillary incisors are on a vertical line through glabella (GALL line) [22]. Individual variation of forehead contour and inclination can influence the position of this landmark and has to be corrected prior to cephalometric measurement. Careful evaluation of these reference landmarks for placement of the vertical line for latter measurement is essential and requires a great understanding of facial balance. Although the correlation of SNB/*B′* and SNPog/Pog′ is highly significant in this current study, the determination coefficients are only $r^2 = .438$ and $r^2 = .429$ (Figure 5(B,C)). In other words, only about 43% of the variation of one point can be justified by the variation of the other. The discrepancy between the skeletal- and the soft-tissue-based measurements can be explained by the difference of soft tissue thickness between the individuals or by intracranial variability. Variation in soft tissue thickness by ethnicity and gender is of great relevance for diagnosis and treatment planning of dentofacial deformities [23]. Cephalometric reference data were also developed for specific ethnic and racial groups [23–25]. To avoid misinterpretation an important point in STCA is that the corresponding norm values were derived from a CG of Caucasian origin, which in the current analysis is not quite ideal because in contrast to the therapy group with pre-existing malocclusions and therefore higher muscle and soft tissue tension subjects of that CG have untreated class 1 occlusion and facially balanced proportions [5,10]. Further patients of the therapy group had brackets that have not been included in the calculation.

When the cranial base is used as the reference line for the measurement of dentofacial parameters, as in SKCA, false findings can be generated because the cranial base (such as NSL) is as variable as the dental and facial structures that it measures. In our study, NSL showed high variation of up to 29° from the horizontal plane. In the literature, similar results have been described with a variation of an anterior skull base inclination of 20° or more in 95% of the considered population [8]. Further results have demonstrated that, in relation to the vertical, the variance of the NSL, FH and palatal and occlusal planes oscillated between 19.2° and 39.8° [8]. Alterations in the variable NSL/TVL are explained by the interindividual irregularity of the sella vertical position, and not of the variability of NHP [26]. In other words, a class II malocclusion with a flat cranial base might be disguised as having normal values for SNB or SNPog when compared with a steep anterior cranial base having small angles. As displayed in Figure 2(A), the NSL showed an inclination of −24.5° relative to the horizontal (perpendicular to TVL), and the differences between SKCA and STCA for the landmarks *A/A′*, *B/B′* and Pog/Pog′ were −12.1, −20.5 and −24.8 mm, respectively. In this case, the NSL-based values showed a greater deficiency when compared with head–posture-based measurements and could therefore possibly influence facial analysis, leading to misinterpretation with respect to further treatment and the amount of advancement of the jaws. In contrast, in Figure 2(B), a flat NSL line produces higher values for SKCA values and overestimates the cranial based measurements. In this case, the angulation of NSL relative to NHP seemed to influence the difference between SKCA and STCA. Thus, the vertical position of the sella can influence the NSL inclination and, consequently, the sagittal position of the mandible and the chin. From a contemporary orthodontic perspective, the angles SNA and SNB have been proposed for use only after correction for the inclination of NSL to the horizontal [8]. To overcome this problem, in cases of obvious variation of the inclination of NSL to FH, any measurement based on NSL should be corrected by the difference between the two planes. For example, if the inclination of NSL to the FH differs significantly from average, any measurements based on NSL should be corrected by this difference. The FH is easy to identify but can also lead to impairment attributable to various locations of reference skeletal landmarks. In our study, the FH is a good estimator of the horizontal, although the values show a high variation of up to 20°. Similar results with a mean craniovertical angulation (FH/VER) in the NHP of 89.6° in males and 90.2 in females, but with high variability, have been described [27]. The variability of planes such as the NSL and FH, related to natural head posture, confirm their relative unsuitability as cephalometric references for clinical purposes and are likely to provide misleading information [4]. Intracranial variability is probably the major cause for the variation of more than half of the measurements between the skeletal-based and the head–posture-based landmarks. In cases of the tilting of NSL and FH, soft tissue landmarks for CA in order to avoid the miss-direction of the planning of orthodontic and orthognathic treatment should be used. A pure soft-tissue-based analysis of the face includes the underlying bone, the position and angulation of the teeth, and the amount of soft tissue covering the hard tissue and reduces the risk of misinterpretation attributable to the variable inclination of skull base structures. Soft tissue landmarks are especially helpful in the most sensitive areas of treatment planning namely the cheek, upper and lower lip and the chin area. Skeletal, dentoalveolar and soft tissue variables and their respective measurements are all integral parts of a comprehensive contemporary lateral CA. The underlying bony structures and the variant, phenotypically dependent, soft tissue thickness has to be integrated into the planning of any surgical intervention. The reliance on only one of the latter aspects can result in an unfavorable improper outcome. Regarding the intra-observer error many authors claim that errors in linear measurements not greater than 1 mm and angular measurements not greater than 1.5° are acceptable. In the present study both measurement parameters showed a very high ICC with minimal random error [8,15,19].

The technical requirements for STCA are minimal and include a laser spirit level, radiopaque markers and software to perform further measurements. The most sensitive and important parts are the reproductive orientation of the head posture and the analysis of the midface, and therefore, the latter requires implementation by experienced personnel only. The short investigation time (head adjustment and measurements) makes this method suitable to be applied under outpatient environmental conditions.

Conclusions

A discrepancy between skeletal and soft tissue CA was found in 75% of measured distances at *A*-point and 56% at *B*- and Pog-point. One possible explanation for this deviations could be given by the variability of cranial-based measurements. Head–posture-based analysis with soft tissue measurements along with facial proportions has the potential to simplify and improve the planning of orthodontic or orthognathic surgery patients.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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