

Original article

Diagnostic concordance between skeletal cephalometrics, radiograph-based soft-tissue cephalometrics, and photograph-based soft-tissue cephalometrics

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Summary

Objective: This study aims to investigate the diagnostic concordance between skeletal cephalometrics and soft-tissue cephalometrics in identifying facial lower third characteristics.

Materials and methods: We compared a skeletal cephalometric analysis (SCA) to a soft-tissue analysis performed on cephalometric radiographs (rSTCA) and to one performed on profile photograph (pSTCA). Ninety-six pre-treatment digital lateral cephalometric radiographs and 96 digital profile photographs were randomly selected for this study (patients' mean age: 18.33, SD: 3.38, age range: 14–29). Inclusion criteria were as follows: no skeletal asymmetry, well-aligned upper and lower dental arches, no history of orthodontic treatment, prosthodontic treatment, facial surgery and trauma, patient's age between 14 and 30 years, high-resolution images, exams taken with natural head position. Kruskal–Wallis and *post hoc* pairwise comparisons tests were used to find differences among the considered cephalometric methods. The diagnostic performance of the three methods was also assessed using the receiver-operating characteristic (ROC) curve analysis.

Results: Significant differences were found between SCA and rSTCA and between SCA and pSTCA in defining sagittal and vertical facial lower third characteristics ($P < 0.05$). No differences were found between rSTCA and pSTCA ($P > 0.05$) for the same facial characteristics. For each parameters investigated, pSTCA showed an area under the curve much closer to the perfect value of 1.00.

Conclusion: Poor diagnostic concordance was found between SCA and rSTCA and between SCA and pSTCA. pSTCA is a reliable method for evaluating the soft-tissue profile characteristics compared to that performed on cephalograms.

Introduction

Over the last decades, facial attractiveness has gained much relevance in orthodontic diagnosis and treatment plan decision making

(1, 2). Soft-tissue cephalometric analysis is considered a reliable diagnostic method not only for orthognathic surgeons but also for orthodontists because it (1) provides information about sagittal and

vertical craniofacial pattern and facial harmony and (2) includes a deepened assessment of soft-tissue profile characteristics (3, 4).

Both skeletal and soft-tissue cephalometric analyses are performed on lateral cephalograms. However, orthodontists are called to consider the risks related to ionizing radiation exposure for each patient (5–8). The British Orthodontic Society recommends the use of cephalometric radiograph only for specific cases rather than for a routinely pre-treatment diagnostic evaluation (9).

Many parameters of the soft-tissue cephalometric analysis can also be assessed on the patients' profile photograph (10, 11). Thus, a photograph-based cephalometric analysis could be helpful for orthodontic treatment planning in those cases where the cephalometric radiograph is not specifically indicated (9). The aim of this study was to compare the diagnosis derived from photograph-based soft-tissue cephalometric analysis to that derived from radiograph-based soft-tissue cephalometrics and to skeletal cephalometrics. The null hypothesis was the absence of differences between the three analyses in defining the sagittal and vertical characteristics of facial lower third.

Materials and methods

This study included right profile digital lateral cephalometric radiographs and photographs of patients selected from the archives of the Department of Orthodontics, 'G. Martino' Hospital, University of Messina, Italy, in the period between January 2013 and May 2015.

The selection criteria were as follows: (1) the absence of reported skeletal asymmetry, (2) minimal dental crowding, (3) no history of previous orthodontic treatment, prosthodontic treatment, facial surgery and trauma, (4) patients' age between 14 and 30 years, (5) digital clinical records with adequate representation of soft-tissue contours, and (6) photographs and radiographs taken with natural head position with teeth in centric occlusion and lips in rest position (10, 11).

Radiographic examinations were executed using ORTHOPHOS XG (Sirona Dental GmbH, Wals bei Salzburg, Austria). Standardized profile photographic records were taken using camera D90 (Nikon Corporation, Minato-ku, Tokyo, Japan) equipped with AF-S VR Micro-Nikkor 105 mm f/2.8G IF-ED (Nikon Corporation, Minato-ku, Tokyo, Japan) and mounted on a levelled tripod. Subjects were instructed to stand on a line drawn on the floor, at a distance of 1.5 m from the camera, and were asked to look into their eyes in a mirror placed 1.2 m in front of them with relaxed lips. All photographic and radiographic records presented, respectively, a resolution of 3216 × 2136 pixels and 2056 × 2600 pixels.

A preliminary analysis on 30 subjects with skeletal Class I malocclusion was run, and the prevalence of normal maxillary sagittal projection for both hard (53 per cent) and soft tissues (20 per cent) was used for power analysis calculation. The analysis indicated that 32 patients were required for each Angle class malocclusion to reach the 80 per cent of power.

From the digital archive, a set of patients was selected based on the inclusion selection criteria ($n = 216$ patients). A preliminary skeletal evaluation was performed by an experienced operator (MB), and three subsets were created according to the \angle ANB cephalometric standards, i.e. 110 Class I subjects (\angle ANB = $2^\circ \pm 2^\circ$), 70 Class II subjects (\angle ANB $> 4^\circ$), and 36 Class III subjects (\angle ANB $< 0^\circ$). This preliminary assessment was performed using the Dolphin Image management software, Version 9.0 (Dolphin Imaging and Management Solutions, Los Angeles, California, USA) and the Steiner's analysis (12).

From each subset, 32 subjects were randomly selected using a web application (www.randomizer.org). A final sample of 96 lateral cephalometric radiographs and 96 profile photographs (27 males, mean age: 18.4; 69 females, mean age: 18.3) were obtained (Table 1).

Two customized analyses were used to compare three cephalometric methods: a skeletal cephalometric analysis (SCA), a soft-tissue cephalometric analysis performed on lateral cephalometric radiograph (rSTCA), and a soft-tissue cephalometric analysis performed on profile photograph (pSTCA; Figures 1 and 2, Table 2). All the methods evaluated the sagittal projection of the maxilla and the mandible and the facial lower third height (4, 12). To compensate the radiograph enlargement, the cephalograms were calibrated using the image of the RX machine built-in ruler.

To compare and calibrate the cephalogram with the patients' profile photo, it was adjusted and superimposed on the patients' photograph. To obtain these adjustments, the following methodology was applied using the software Adobe Photoshop CC (Adobe Systems Software Ireland Ltd, Citywest Business Campus, Dublin, Ireland): (1) identification of soft-tissue subnasal and B' point landmarks on photograph and radiograph, (2) superimposition of radiograph on patient's photo, (3) increase of radiographic image transparency, (4) orientation of the radiographic and photographic images, aligning B' point and subnasal landmarks, and (5) transfer of radiographic image calibration landmarks on photographic image (CP1 and CP2 points; Figure 3).

The diagnosis for the SCA, rSTCA, and pSTCA was set for each patient according to the standard value of:

1. Normal position, protrusion, and retrusion for sagittal maxillary and mandibular projection.
2. Mesofacial, brachyfacial, and dolichofacial for facial lower third height (Table 2).

Each analysis was performed by an experienced operator (ALG) who was not aware of the details related to the preliminary skeletal evaluation. Thirty cephalograms and 30 profile photographs were randomly selected, superimposed and retraced to assess intra-operator and inter-operator reliability. Paired *t*-test and Spearman's correlation analysis were applied between the two measurements for each parameter of SCA, rSTCA, and pSTCA. No differences ($P > 0.05$) were found between the two readings with a correlation

Table 1. Characteristics of patients included in the present study.

Sample groups	Sample characteristics		
	Size	Mean age (years)	Range (years)
Total	96 (male 27; female 69)	18.07 (SD 3.38)	14–29
Angle class I	32 (male 7; female 25)	19.21 (SD 4.17)	14–29
Angle class II	32 (male 4; female 28)	17.31 (SD 3.09)	14–26
Angle class III	32 (male 16; female 16)	17.68 (SD 2.45)	14–23

index ranging from 0.952 to 0.941 for intra-operator variation and from 0.915 to 0.882 for inter-operator variation. The method error was also assessed using Dahlberg's formula (13). For angular measurements, the method error was 0.62 degree, while it ranged from 0.4 to 1.1 mm for linear measurements.

Data analysis was performed using SPSS Statistics software (IBM Corporation, Armonk, New York, USA). Normal distribution of data was preliminarily checked. Kruskal–Wallis one-way analysis of variance (ANOVA) was used to verify if the diagnosis was affected by the three different cephalometric methods. *Post hoc* pairwise comparisons were calculated to find individual differences among the considered cephalometric methods. The level of significance was set at $P < 0.5$.

Finally, the receiver-operating characteristic (ROC) curve analysis was used to assess the diagnostic performance of SCA and pSTCA compared to rSTCA.

Results

The cephalometric method was found to affect the diagnostic outcomes ($P < 0.05$) as revealed by the Kruskal–Wallis one-way

ANOVA. Performing *post hoc* pairwise comparisons, significant differences were found between SCA and rSTCA and between SCA and pSTCA in defining sagittal maxillary projection ($P < 0.05$), sagittal mandibular projection ($P < 0.05$), and facial lower third height ($P < 0.05$; Table 3). No differences were found between rSTCA and pSTCA ($P > 0.05$) for the same diagnostic parameters (Table 3). Distribution of diagnostic outcomes obtained with the three methods is reported in Table 4.

The sensitivity and specificity of SCA and pSTCA are plotted in Figure 4, and the areas under the ROC curves are reported in Table 5. For each parameter investigated, pSTCA showed an area under the curve much closer to 1.00, which is the value that a perfect diagnostic method should have. SCA showed a very low area under the curve for the identification of the sagittal projection of the maxilla and the mandible and a significant curve for the identification of facial lower third.

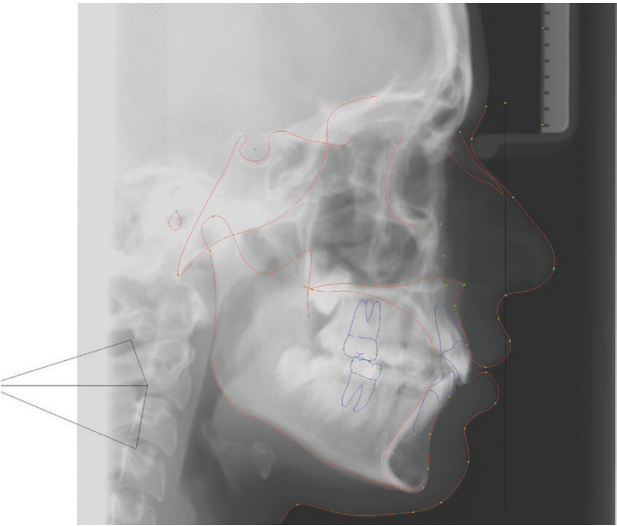


Figure 1. Cephalometric tracing of the skeletal analysis (SCA) and soft-tissue analysis performed on radiograph (rSTCA). The following measurements were evaluated: SNA°; SNB° and ANS-Me for SCA; A' to TVL; B' to TVL; and Sn to Me' for rSTCA.



Figure 2. Cephalometric tracing of soft-tissue analysis performed on photograph (pSTCA). The following measurements were evaluated: A' to TVL; B' to TVL; and Sn to Me'.

Table 2. Cephalometric parameters and diagnosis used to evaluate the concordance between (SCA) and soft-tissue cephalometric analysis performed on cephalogram (rSTCA) and on photograph (pSTCA). A' = maxillary point; B' = mandibular point; Me' = menton; SN = subnasal; TVL = true vertical line.

Cephalometric parameters and diagnostic synthesis for female subjects					
Facial characteristics	SCA*	(p-r) STCA**	Diagnosis and standard values		
Sagittal maxillary projection	SNA°	A' to TVL (mm)	Retrusion	Normal	Protrusion
			SNA (°) < 78.5	SNA (°) 82 ± 3.5	SNA (°) > 85.5
Sagittal mandibular projection	SNB°	B' to TVL (mm)	A' to TVL (mm) < -0.9	A' to TVL (mm) 0.1 ± 1.0	A' to TVL (mm) > 1.1
			Retrusion	Normal	Protrusion
Facial low third height	ANS-Me (mm)	SN to Me' (mm)	SNB (°) < 77.5	SNB (°) 80.9 ± 3.4	SNB (°) > 84.3
			B' to TVL (mm) < -6.8	B' to TVL (mm) -5.3 ± 1.5	B' to TVL (mm) > -3.8
			Brachyfacial	Mesofacial	Dolichofacial
			ANS-Me (mm) < 60.5	ANS-Me (mm) 65 ± 4.5	ANS-Me (mm) > 69.5
			SN to Me' (mm) < 67.6	SN to Me' (mm) 71.1 ± 3.5	SN to Me' (mm) > 74.6

*Measurements from Steiner's analysis. **Measurements from Arnett's soft-tissue analysis.

Discussion

To the best of our knowledge, this is the first study that (1) investigates the diagnostic concordance between different cephalometric methods (rather than the correlation between cephalometric parameters) and (2) compares the diagnosis obtained with two soft-tissue analyses performed on photographs and on cephalograms.

The effectiveness of a diagnostic record can be tested only by assessing its validity and consistency in identifying the disease (14, 15). However, neither malocclusion nor facial disharmony represents a pathological condition (16). Also, malocclusion cannot be defined through universally accepted standards. This means that, in orthodontics, it is not possible to evaluate the validity of diagnostic records. In the absence of a true state of disease, a comparative analysis of concordance between diagnostic methods represents a suitable alternative to investigate their effectiveness (14, 15).

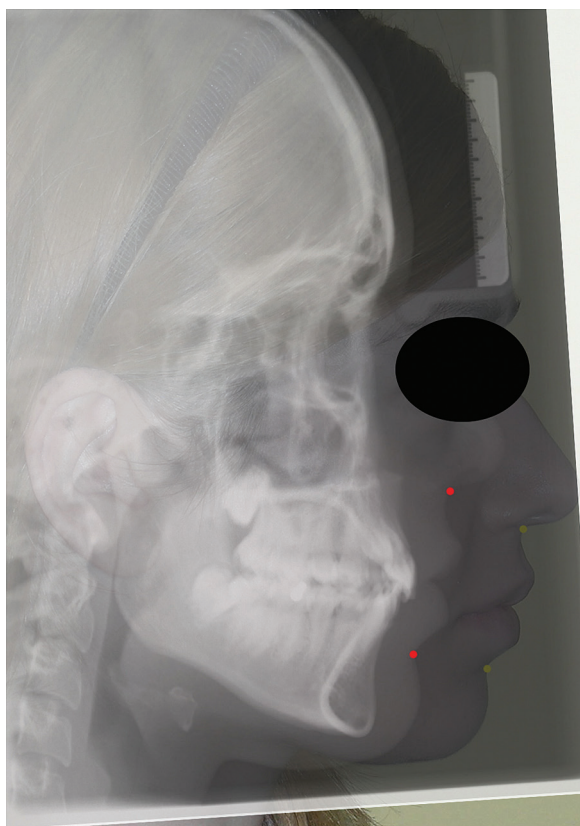


Figure 3. Superimposition of lateral cephalometric radiograph on profile photograph.

The results of this study indicate that skeletal cephalometrics (SCA) and soft-tissue cephalometrics (pSTCA and rSTCA) differ significantly in defining the patient's facial characteristics (Tables 3 and 4). This suggests a poor diagnostic concordance between hard- and soft-tissue analyses, rejecting the null hypothesis of this study.

It is demonstrated that facial profile is highly influenced by soft tissue that behaves independently from the underlying skeleton because of the individual differences in thickness (1, 17). This could explain the differences found in this study between SCA and the considered soft-tissue cephalometric analyses (rSTCA and pSTCA).

Thus, it becomes relevant to establish which analysis can be more suitable to achieve an appropriate diagnosis and, consequently, an adequate treatment plan. The needs of orthodontic patients are primarily aesthetic needs (1, 18), and one of the potential advantages of soft-tissue cephalometric analysis is the possibility of evaluating the perceived facial aesthetic (10–11, 19–20). On the contrary, skeletal pattern imbalance does not necessarily correspond to undesirable aesthetics (21). Moreover, orthodontic treatment based on cranial base standards does not always determine an improvement of facial aesthetics (22, 23); sometimes, it can even lead to undesirable facial outcomes (22, 23).

The ROC analysis was performed setting as gold standard the soft-tissue cephalometric analysis performed on cephalogram. This choice was taken because soft-tissue cephalometric analysis was originally described on cephalograms (3–4) and for the above-mentioned aesthetic influence of soft-tissue profile (10–11, 19–20).

ROC analysis revealed a significant sensitivity and specificity of SCA only for the facial lower third height parameter (Figure 4), suggesting a reduced impact of soft-tissue variables for the evaluation of vertical dimension (24). Also, ROC analysis indicated high sensitivity and specificity of pSTCA for all parameters investigated (Figure 4). This result suggests that the soft-tissue analysis performed on photographs is a reliable method to thoroughly evaluate soft-tissue profile.

Table 3. *P* value for pairwise comparisons (*post hoc*) between skeletal cephalometrics (SCA), radiograph-based cephalometrics (rSTCA), and photograph-based cephalometrics (pSTCA). ns = non-significant.

Facial structures	Pairwise comparisons (<i>post hoc</i>)	
Maxilla	SCA versus rSTCA	$P < 0.05$
	SCA versus pSTCA	$P < 0.05$
	pSTCA versus rSTCA	ns
Mandible	SCA versus rSTCA	$P < 0.05$
	SCA versus pSTCA	$P < 0.05$
	pSTCA versus rSTCA	ns
Facial lower third	SCA versus rSTCA	$P < 0.05$
	SCA versus pSTCA	$P < 0.05$
	pSTCA versus rSTCA	ns

Table 4. Distribution of diagnostic outcomes obtained with skeletal cephalometrics (SCA), radiograph-based soft-tissue cephalometrics (rSTCA), and photograph-based soft-tissue cephalometrics (pSTCA).

Facial structures	Diagnosis	SCA ($n = 96$)	rSTCA ($n = 96$)	pSTCA ($n = 96$)
Maxilla	Normal	48 (50%)	24 (25%)	25 (26.04%)
	Protrusion	14 (14.58%)	1 (1.04%)	0 (0%)
	Retrusion	34 (35.41%)	71 (73.95%)	71 (73.95%)
Mandible	Normal	50 (52.08%)	16 (16.66%)	17 (17.70%)
	Protrusion	8 (8.33%)	13 (13.54%)	12 (12.5%)
	Retrusion	38 (39.58%)	67 (69.79%)	67 (69.79%)
Facial lower third	Mesofacial	47 (48.95%)	21 (21.87%)	21 (21.87%)
	Dolichofacial	27 (28.12%)	4 (4.16%)	3 (3.12%)
	Brachyfacial	22 (22.91%)	71 (73.95%)	72 (75%)

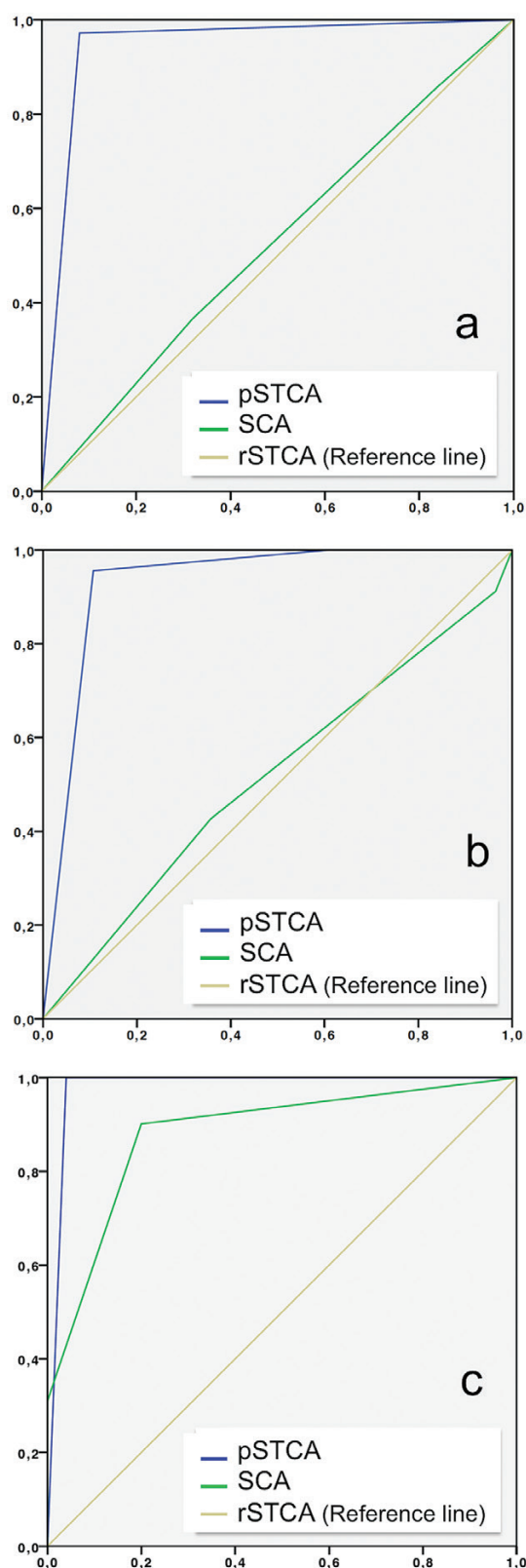


Figure 4. Receiver-operating characteristic (ROC) analysis. Sensitivity and specificity of skeletal cephalometrics (SCA) and photograph-based soft-tissue cephalometrics (pSTCA): (a) maxillary sagittal projection, (b) mandibular sagittal projection, and (c) lower third height.

Another advantage of the photograph-based soft-tissue cephalometric analysis is the possibility to reduce the patient's radiation

Table 5. Area under the curve for each parameters investigated by skeletal cephalometrics (SCA) and photograph-based soft-tissue cephalometrics (pSTCA). CI = confidence interval.

Facial structures	Diagnostic methods (test variable)	Area under curve with 95% CI
Maxilla	SCA	0.526 (0.394–0.658)
	pSTCA	0.946 (0.880–1.000)
Mandible	SCA	0.517 (0.393–0.641)
	pSTCA	0.933 (0.863–1.000)
Facial lower third	SCA	0.882 (0.805–0.958)
	pSTCA	0.980 (0.935–1.000)

exposure compared to the execution of standard cephalograms. Moreover, the reproducibility of diagnostic conclusions and of treatment plan strategies does not seem to be influenced by the availability of cephalograms (25–28). There is no evidence regarding lateral cephalometric radiographs in enhancing the prediction of results, treatment quality, and time reduction (26).

As reported by the Directive 97/43/EURATOM, radiographic exposure is justified only when the management of the patient depends on the information obtained from the radiograph. According to our findings, the execution of the lateral cephalogram is not justified when the intent of the clinicians is to evaluate facial profile characteristics.

The necessity of individually based selection criteria for cephalometric radiography has been proposed as a solution to reduce unproductive radiographs (28). These selection criteria should be based on scientific evidence such as that provided by this study.

Conclusion

1. Skeletal cephalometrics and soft-tissue cephalometrics lead to different diagnoses of patients' facial characteristics.
2. Soft-tissue analysis performed on photographs is a reliable method to evaluate soft-tissue profile compared to that performed on cephalograms.

Conflict of interest

None to declare.

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