Original Article

Cephalometric and In Vivo Measurements of Maxillomandibular Anteroposterior Discrepancies: A Preliminary Regression Study

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Abstract: One of the aims of the present investigation was to assess three-dimensionally the anteroposterior discrepancy of dental bases using a noninvasive direct procedure. A second aim was to verify the relationship of three-dimensional soft-tissue measurement to the well-established two-dimensional cephalometric assessments of anteroposterior discrepancy. Dental and facial landmarks were directly digitized on 20 orthodontic and maxillofacial surgery patients aged 8 to 26 years using an electromagnetic three-dimensional computerized digitizer. The anteroposterior maxillomandibular discrepancy was measured by calculating the linear distances between the projections of subnasal and sublabial landmarks on the occlusal plane, subnasal and sublabial landmarks on Camper's plane, and insertion of maxillary and mandibular median labial frenula on the occlusal plane. From lateral cephalograms of the same patients, the following measurements were obtained: subspinale point-nasion-supramentale point (ANB) angle; corrected ANB angle that compensates for the position of the maxilla and rotation of the mandible relative to the cranial base; Wits appraisal; MM-Wits, linear distance between the projections of points A and B on the bisector of the palatal plane to mandibular plane angle; and soft-tissue Wits, linear distance between the projections of soft-tissue points A and B on the bisecting occlusal plane. The best two-dimensional vs three-dimensional linear regression ($r = 0.91$) was found between Wits appraisal and the linear distances between the projections of maxillary and mandibular median labial frenula on the occlusal plane (Wits $= -1.05 \times$ 3D measurement $- 3.75$). The three-dimensional evaluation of the sagittal discrepancy of the jaws directly performed in vivo may allow a more complete analysis of a patient's soft-tissue drape together with the underlying hard-tissue structure. (*Angle Orthod* 2002;72:579–584.)

Key Words: Jaw relationships; Two-dimensional; Three-dimensional

INTRODUCTION

The diagnostic methods currently used in dentistry need to possess some new qualities that were not required in the past. Whenever possible, a quantitative and three-dimensional approach, a minimally invasive and disturbing procedure, and a low-cost/high benefit plan are demanded by modern healthcare standards.

The assessment of the global anatomic situation of the patient should analyze the sagittal discrepancy between the maxilla and the mandible, a factor playing a major role in the diagnosis of facial disharmonies.[1–6]

Among the diverse cephalometric linear and angular measurements proposed, no single value seems to provide an assessment that is at the same time easy and provides reliable anatomical measurements of sufficient clinical significance.[4,7] The two best-known measurements, and the most frequently quoted by both researchers and clinicians, seem to be the subspinale point-nasion-supramentale point (ANB) angle and the linear distance between the projections of the same points A and B on the occlusal plane (Wits appraisal).[6,8]

Both of them have been reported to have several short-

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Accepted: May 2002. Submitted: April 2002.

comings.[2,8] To overcome these limitations, several new reference planes, linear distances, and angles have been proposed. For instance, the ANB angle has been corrected for the position of the maxilla (sella-nasion-subspinale angle) and rotation of the mandible (sella-nasion-mandibular plane angle) relative to the cranial base.[1,9,10] Hall-Scott[11] projected the points A and B on the bisector of the angle between the palatal plane and the mandibular plane, and measured this anteroposterior discrepancy.[6,8,11] Nanda and Merrill[12] used the palatal plane for the projection of the same points A and B and measured this difference. Yang and Suhr[3] measured the angle between the A-B plane and the Frankfurt plane. Chang[13] projected the same points on the Frankfurt plane. A further proposal used the anteroposterior dysplasia indicator, which considers the facial angle (nasion-pogonion to Frankfurt plane), the A-B plane angle, and the palatal plane angle.[2]

A complete assessment should not be limited to the hard-tissue relationships but should also consider the contribution of the patient's soft-tissues.[14] Indeed, soft-tissue cephalometric measurements were also performed in orthodontic patients, and the cutaneous analogs of both the ANB angle (subnasal–soft-tissue nasion–sublabial[15]), and the Wits appraisal (subnasal and sublabial projected on the occlusal plane[5]) have been used.

Technology provides three-dimensional noninvasive digitizers that can be used directly on human subjects to supply the metric coordinates of landmarks.[16–20] The coordinates could then enter any kind of mathematical modeling. The correlation between classic cephalometric measurements, which are invasive and limited to two-dimensional assessments, and new soft-tissue measurements, which permit a three-dimensional approach with no damage to the patient, should be analyzed. For instance, in a previous investigation two-dimensional vs three-dimensional correlations were studied in a group of adult men using an optoelectronic instrument that was limited to facial cutaneous landmarks.[17]

Currently, electromagnetic digitizers allow studying the position of the occlusal plane together with the three-dimensional arrangement of the anterior-posterior jaw relationships.[6] In the present preliminary investigation, an electromagnetic three-dimensional computerized digitizer has been used to digitize several dental, oral, and facial landmarks in a group of orthodontic and maxillofacial surgery patients. From the landmark coordinates, assessments of the anteroposterior discrepancy of dental bases have been made. The three-dimensional measurements have been related to conventional two-dimensional cephalometric assessments. The method could supplement conventional diagnostic procedures.

MATERIALS AND METHODS

Sample

After a detailed description of the procedures involved in the experiment, 20 orthodontic and maxillofacial surgery patients (14 males, six females) aged between 8 and 26 years (mean 15.3 years, SD 7.0) signed a consent form. For the patients aged less than 18 years, informed consent was obtained from the parents or legal guardians. The investigation did not include any adjunctive potentially harmful procedure (apart from the cephalometric radiographs that were taken for diagnostic and therapeutic purposes), and the local ethics committee approved it.

A lateral cephalometric radiography and a three-dimensional analysis of facial soft-tissues were performed in all subjects. In all the subjects, both examinations were performed within 1 week.

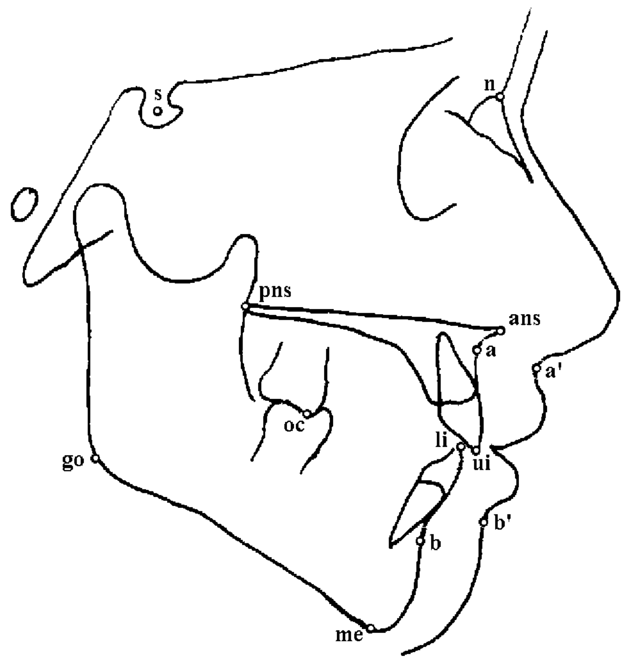

FIGURE 1. Digitized landmarks. N indicates nasion; S, sella; ANS, anterior nasal spine; PNS, posterior nasal spine; A, A′, subspinale point and cutaneous analog; B, B′, supramentale point and cutaneous analog; Me, Menton; Go, Gonion; LI, lower incisor; UI, upper incisor; Oc, first permanent molar occlusal point.

Cephalometric measurements

Lateral cephalograms for all patients were obtained in the standing posture, with a final enlargement of 10%. Measurements were not corrected for radiographic enlargement.

A single operator traced and digitized several standardized cephalometric landmarks on the prints (Figure 1) by a semiautomatic image analyzer. Linear and angular measurements were obtained by a computerized program that is currently in use in our laboratory.[5,6,16]

Among others, the following measurements were selected and analyzed:

- ANB (subspinale-nasion-supramentale) angle (°);
- Corrected ANB angle (ANB*, °): ANB* = original ANB angle $+ 0.5 \times (81.5° - $ SNA angle$) + 0.25 \times (32° -$ SN-GoMe angle);[1,9,10]

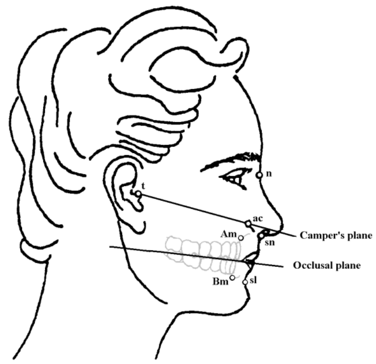

FIGURE 2. Digitized facial landmarks and measured planes. Landmarks: n indicates nasion; sn, subnasal; sl, sublabial; ac_r, ac_l, nasal alar crest; t_r, t_l, tragion; am, insertion of maxillary median labial frenulum; bm, insertion of mandibular median labial frenulus. The left-side projections of Camper's (t-ac) and occlusal planes are indicated.

- Wits appraisal (linear distance in millimeters between the projection of points A and B on the bisecting occlusal plane, ie, the plane bisecting molar and incisor overbite);
- A-B on MM° bisector (MM-Wits): linear distance in millimeters between the projections of points A and B on the bisector of the angle between the palatal (maxillary) plane and the mandibular plane (ANS-PNS to Go-Me);[6,8,11] and
- Soft-tissue Wits appraisal: linear distance in millimeters between the projections of soft-tissue points A′ and B′ on the bisecting occlusal plane.[5]

Digitization of soft-tissue landmarks

Several soft-tissue facial, oral, and dental landmarks were digitized on each subject. A detailed description of the procedure can be found in Ferrario et al.[19] Before digitization, a single operator located the facial landmarks by careful inspection or palpation and marked them on the cutaneous surface.

Data collection was performed in two separate steps. First, the subjects sat relaxed on a wooden chair with the head in the natural head position (NHP). To obtain the NHP, a 25×25–cm^2 mirror was positioned at eye level at a distance of about 1.5 m, and the subject was invited to look at the reflection of his/her pupils. The head was then fixed in the NHP to the chair back by a wood and foam head-frame. The subjects were then asked to close their eyes, swallow, keep their teeth in contact (centric occlusion), and not move for the data collection procedure (about 60 s).

The following facial landmarks were digitized (Figure 2):

- Median points—n, nasion; sn, subnasal; sl, sublabial; and
- Lateral points (right- and left-side noted r and l)—ac_r, ac_l, nasal alar crest; t_r, t_l, tragion.

At the end of this first sequence, the lips of the subject were opened using a gag, his/her head was fixed again by the head-frame in a position suitable for the collection of the second sequence of landmarks, and the following facial, oral, and dental landmarks were digitized while the subject maintained the position with closed eyes:

- Facial landmarks—n, nasion; t_r, t_l, right- and left-side tragion;
- Oral landmarks—Am, Bm, gingival attachment of maxillary and mandibular median labial frenula; and
- Right- and left-side maxillary dental landmarks—11, 21, 12, 22, midpoints of incisal edges; 13, 23, canine cusps; 16, 26, mesiobuccal cusp of first molars.

This second acquisition lasted about 120 s for each subject.

The three-dimensional (x, y, z) coordinates of the landmarks were then obtained with a three-dimensional electromagnetic digitizer (3Draw, Polhemus Inc., Colchester, Vt) interfaced with a computer. The system has a resolution of 0.013 cm/cm of range and an accuracy of 0.025 cm, and it supplies real metric data independent of external reference systems.[18,19] A single operator did the digitization of the landmarks.

Mathematical calculations

Two separate digitizations were necessary because the use of the gag made difficult or even impossible the detection of some of the facial landmarks (most of all subnasal and sublabial), and it modified the subject's NHP.[19] A computer program took the coordinates of the three points (nasion, left and right tragi) common to both data acquisitions (fiducial points) and referred all coordinates to a single reference system (the subject's head in NHP), as described by Ferrario et al.[16]

The orientations of Camper's plane (from the midpoint between the two nasal alar crests, landmarks ac_r and ac_l, to the two tragi, landmarks t_r and t_l) and of the occlusal plane (the plane passing through the center of gravity of the maxillary incisors and canines and the digitized cusps of the maxillary first molars, landmarks 16 and 26) were calculated.[19]

The following measurements were then obtained:

- Soft-tissue Wits appraisal (skeletocutaneous class, linear distance in millimeters between the projections of subnasal and sublabial landmarks on the sagittal projection of the occlusal plane);[5,19]
- Camper Wits (cutaneous class, linear distance in millimeters between the projections of subnasal and sublabial landmarks on the sagittal projection of Camper's plane);[19]
- Am-Bm Wits (skeletal class, linear distance in millimeters between the projections of the insertion of maxillary and mandibular median labial frenula on the occlusal plane).

TABLE 1. 2D Cephalometric and 3D Direct Assessments of Maxillo-mandibular Anteroposterior Discrepancy in 20 Patients

	Unit	Mean	SD	Min	Max
Cephalometry[a]					
ANB	degrees	3.63	0.88	−6.9	7.9
ANB*	degrees	3.45	0.74	−4.9	7.9
Wits	mm	0.03	5.84	−13.0	7.2
MM-Wits	mm	−1.90	6.34	−16.2	4.3
Soft-tissue Wits	mm	3.55	5.48	−8.5	10.5
Direct 3D					
Soft-tissue Wits	mm	−4.89	5.64	−10.1	7.0
Camper Wits	mm	−4.37	5.96	−17.4	8.3
Am-Bm Wits	mm	−3.61	5.10	−9.5	8.9

[a] ANB*: corrected ANB angle. ANB* = original ANB angle + 0.5 × (81.5° − SNA angle) + 0.25 × (32° − SN-GoMe angle).

TABLE 2. Linear Regression Analysis Between 2D Cephalometric and 3D Direct Assessments in 20 Patients: Regression Coefficients and Relevant Standard Errors

	Direct 3D		
Cephalometry[a]	Soft-tissue Wits	Camper Wits	Am-Bm Wits
ANB	0.691 (0.361)	0.602 (0.327)	0.794 (0.429)
ANB*	0.794 (0.508)	0.641 (0.402)	0.847 (0.581)
Wits	0.767 (0.274)	0.531 (0.208)	0.914 (0.433)
MM-Wits	0.814 (0.279)	0.632 (0.209)	0.881 (0.343)
Soft-tissue Wits	0.868 (0.378)	0.758 (0.288)	0.860 (0.368)

[a] ANB*: corrected ANB angle. ANB* = original ANB angle + 0.5 × (81.5° − SNA angle) + 0.25 × (32° − SN-GoMe angle). All regressions are significant at the .001 level.

Statistical analysis

Descriptive statistics (mean, standard deviation, skewness, and kurtosis) were computed for all cephalometric and direct measurements. Angular variables were analyzed using the rectangular components of angles (sine and cosine) and the relevant circular statistics.[21] Linear regression analyses were made between the two-dimensional cephalometric (dependent variable to be estimated) and the three-dimensional soft-tissue (independent variable, directly measured) measurements. Significance was set at 5% ($P \leq .05$). All the calculations were performed using original computer programs devised and written by one of the authors (Ferrario).

Method error

The only source of error of the present investigation was in the digitization of the landmark coordinates because computerized algorithms with negligible errors of approximation automatically performed all subsequent procedures. This procedure is regularly performed in the laboratory for quality certification, and it has been detailed elsewhere.[5,6,19]

In brief, for three-dimensional coordinates, repeated digitizations (with a 1-week interval) of the same four subjects (two males, two females) gave Dahlberg's errors between 0.4–1.3 mm and percentage errors between 0.6–5.3%.[19] For two-dimensional coordinates, the repeated digitizations (with a 1-month interval) of a random sample of 30 radiographs gave differences up to 2 mm (on average, 1.2 mm), whereas the repeated tracings of the same radiographs gave differences up to 2.5 mm (on average, 1.8 mm).[5,6] Overall, the method appeared to be reliable.

RESULTS

Table 1 reports the descriptive statistics of the analyzed variables. Overall, a large variability was found for all measurements, with ranges up to 15° and 60 mm. All variables were approximately normally distributed, with absolute skewness (asymmetry of the distribution, 0 in perfectly symmetric distributions) ranging from 0.11 to 0.67. Kurtosis (height of the distribution, 3 in normal distributions) ranged from 2.06 to 2.88.

Linear correlation analyses were made between pairs of two-dimensional cephalometric and in vivo three-dimensional soft-tissue assessments of anterior-posterior discrepancy. All correlations were significant at the 0.1% level. The regression coefficients and relevant standard errors are listed in Table 2, whereas the slope and intercept of each regression equation ($Y = mX + q$, where Y is the estimated cephalometric variable and X is the soft-tissue measured variable) are given in Table 3 together with the relevant standard errors.

Overall, the best correlations were those between the Am-Bm Wits (skeletal class, projection of Am and Bm on the occlusal plane) and the cephalometric measurements, with coefficients of correlation larger than 0.79. This means that at least 62% of the variance of the cephalometric assessment can be explained by the direct three-dimensional measurement. Apart from the ANB angles (both conventional and corrected), in all occasions a nearly 1:1 relationship was found, with slopes of the regression equations ranging between 43° and 48°. The highest coefficient of correlation ($r = 0.91$) was found between the three-dimensional Am-Bm Wits and the two-dimensional Wits appraisal.

The two direct measurements that combined hard- and soft-tissue structures (namely, the three-dimensional linear distances between the projections of subnasal and sublabial on the occlusal [soft tissue Wits] plane and Camper's [Camper Wits] plane) performed best when correlated to a cephalometric assessment that also considered the soft-tissue profile drape (namely, the two-dimensional soft-tissue Wits appraisal).

DISCUSSION

The conventional assessments of the anteroposterior discrepancy of the middle (maxilla) and lower (mandible) facial thirds are usually limited to the skeletal configuration,

TABLE 3. Linear Regression Analysis Between 2D Cephalometric and 3D Direct Assessments in 20 Patients: Slope (m), Intercept (q) and Relevant Standard Errors

		Direct 3D (X)		
Cephalometry (Y)[a]		Soft-tissue Wits	Camper Wits	Am-Bm Wits
ANB	m	−0.483 (0.015)	−0.398 (0.013)	−0.613 (0.019)
	q	1.268 (0.108)	1.891 (0.091)	1.416 (0.119)
ANB*	m	−0.469 (0.021)	−0.358 (0.016)	−0.553 (0.026)
	q	1.163 (0.152)	1.892 (0.112)	1.459 (0.161)
Wits	m	−0.794 (0.011)	−0.521 (0.008)	−1.046 (0.020)
	q	−3.854 (0.082)	−2.243 (0.058)	−3.746 (0.120)
MM-Wits	m	−0.915 (0.011)	−0.673 (0.008)	−1.096 (0.015)
	q	−6.375 (0.084)	−4.837 (0.059)	−5.856 (0.095)
Soft-tissue Wits	m	−0.843 (0.015)	−0.697 (0.011)	−0.923 (0.017)
	q	−0.570 (0.113)	0.508 (0.081)	0.216 (0.102)

[a] ANB*: corrected ANB angle. ANB* = original ANB angle + 0.5 × (81.5° − SNA angle) + 0.25 × (32° − SN-GoMe angle). All regressions (Y = mX + q) are significant at the .001 level.

and do not take the soft-tissue facial profile into consideration.[3] Indeed, although the underlying hard-tissue structure establishes most of the facial configuration, the actual appearance of the patient's face also results from the cutaneous contribution.

Maxillofacial surgeons and orthodontists have always been interested in recording facial morphology and understanding the anatomical basis of facial appearance in its entirety, including both the underlying hard-tissue and the soft-tissue drape.[4,22] Indeed, a close relationship of the soft-tissues with the underlying skeletal pattern might not exist, and a careful evaluation of the soft-tissue drape is mandatory.[3,4,14,15,22–24]

Nevertheless, some investigators found a correlation between cutaneous and skeletal assessments of anterior-posterior jaw discrepancy, particularly between the ANB angle and its soft-tissue equivalent.[15,17]

The present investigation aimed at defining a new method that could support some of the existing diagnostic procedures, and the correlation between conventional two-dimensional hard-tissue measurements and soft-tissue three-dimensional assessments has been analyzed.

Three-dimensional data have been collected by an electromagnetic digitizer, which appears to be among the best instruments for computerized anthropometry in human subjects.[19]

Indirect computerized anthropometry usually collects each landmark only once, independent of the number of measurements. In the present study, three cutaneous landmarks had to be digitized twice because it was impossible to obtain in a single session both the dental and the soft-tissue landmarks next to the lips and on the nose. Indeed, not only did the use of the gag partially modify the positions of lips, nose, and chin but the subject head position also had to be changed from the NHP into a more suitable position for the digitization of the dental landmarks. A mathematical superimposition between the two separate digitizations was then performed.[16]

The protocol used in the present investigation appeared reproducible, with limited errors. Two factors influence the repeated digitization of landmarks in vivo: subject's position and operator error. Both of them are of concern in a clinical setting. The use of the NHP should limit the first source of error because this position is one of the most reproducible.[16] Operator error could be limited by well-defined protocols, with limited allowance for individual decisions.

The main limitation of the present study was the reduced number of analyzed patients, which prevented splitting up into different age and sex groups. Nevertheless, for all analyzed variables a wide range of measurements was found, with approximate normal distributions (Table 1). All the following considerations, therefore, should be considered preliminary, and only studies performed with a larger number of patients may allow conclusions that are more significant.

A radiographic analog of the soft-tissue Wits (skeletocutaneous class, projection of soft-tissue points A′ and B′ on the occlusal plane) has already been found to be significantly correlated to the conventional Wits appraisal and less variable than it.[5]

The distances between the projections of the subnasal and sublabial landmarks on the occlusal (soft-tissue Wits, skeletocutaneous class) and Camper's (Camper Wits, cutaneous class) planes had already been found to be significantly correlated, with a nearly one-to-one relationship.[19]

Camper Wits was assessed to supply an entirely external method for the quantitative evaluation of jaw discrepancies.[5] The Am-Bm Wits (skeletal class, projections of the insertion of maxillary and mandibular median labial frenula on the occlusal plane) should correspond to the conventional Wits appraisal. Indeed, the correlation coefficient between the two measurements was the best one found in the current study (Table 2), with a regression slope of 46°, which corresponds to a nearly one-to-one relationship (Table 3).

CONCLUSION

The good correlation between skeletal and soft-tissue assessments of maxillomandibular sagittal relationships found in the present, preliminary patient group raises the question of whether a standardized protocol for a noninvasive facial morphology analysis could replace, at least in part, X-ray cephalometric analysis.[15] Soft-tissue appraisals could be adequate for standard diagnoses and treatment planning in most orthodontic patients and even in the follow-up of surgical patients. The equations listed in Table 3 may be used to estimate cephalometric measurements, with a limited standard error of the estimate.

The procedure could be repeated several times during treatment without any additional biologic cost for a patient, thereby monitoring the modifications induced in the soft-tissue and dental structures. More invasive examinations (from standard X-ray cephalometric analysis to three-dimensional computerized tomography scan reconstruction) could be limited to the first assessment of severe malocclusions where a combined orthodontic and surgical protocol is needed.

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