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Quantitation of transverse maxillary dimensions using computed tomography: a methodological and reproducibility study

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SUMMARY The present investigation was a methodological study of a new method of quantification of a series of factors in the transverse dimension of the maxilla including the nose, maxillary bones and dental arches, based on computer tomographic (CT) scanning. The aim was to investigate a series of parameters thought to be relevant in the differential diagnosis of discrepancies in the morphology of this area and probably affected by orthodontic appliances.

Based on a standardized CT scanning registration of 10 subjects, a series of points on the scans were identified and then measured in a special cephalometric computer system (linear and angular values). The quantitation was repeated by each observer and inter- and intra-observer differences were calculated.

The results demonstrated that virtually all the parameters showed a high degree of reproducibility at both levels and confirmed the statistical suitability of the method described. The method will be used in a series of ongoing studies regarding the morphology and treatment of discrepancies of the midface and therefore supplement the relatively sparse information based on quantitative reports concerning this important anatomical area.

Introduction

Orthodontic diagnosis is primarily based on a morphological and quantitative description of structures in three planes, namely sagittal, vertical and transverse (Angle, 1907). In the first two planes, the lateral cephalogram provides material that can be quantitated as linear or angular variables and, thus, forms the basis of the cephalometric analysis generally used in orthodontic diagnosis. The transverse dimension is naturally of equal importance in the formation of the occlusion. Anomalies in maxillary transverse dimensions lead to occlusal problems including crossbite and scissors bite with or without mandibular forced bite. Corrections of these anomalies are generally considered some of the most important in orthodontics. The narrow skeletally small maxilla is often related to an increased vertical jaw relationship and predisposes to open bite and possibly a Class III skeletal relationship. In the same way that the diagnosis and treatment of sagittal and vertical discrepancies, as well as their differential diagnoses, include considerations of skeletal structures as well as dento-alveolar structures, these also should be identified and treated in transverse anomalies. The basic problem has been to create a radiographic measurement on which these structures can be measured.

The frontal or postero-anterior radiograph, while occasionally used in the quantitation of cranial morphology (Athanasiou, 1986), does not reveal corresponding information, due to the superimposition of many structures from different planes of space, as well as difficulties in defining structures for measurement. In the past, implant studies have been used to investigate the development of the maxillary complex (Björk and Skieller, 1977) or the reaction of the structures to orthopaedic forces (Krebs, 1958; Skieller, 1964), although for ethical reasons this type of study cannot now be performed. Timms (1980), in a study of rapid maxillary expansion, used computed tomography (CT) for the first time and concluded that the method warranted further investigation.

The aim of the present study was to develop and evaluate a simple non-invasive technique for accurate and reproducible evaluation of maxillary structures based on a series of frontal CT scans. Using a series of parameters, the reproducibility of the quantitation method was evaluated at three levels: (1) variation due to the computer/digitizing process; (2) intra-observer variation; (3) inter-observation variation.

Subjects and method

The present study was based on CT registration of 10 adults (three males, seven females), average age 26 years 3 months (minimum 22 years 1 month; maximum 31 years 6 months). The subjects were chosen irrespective of occlusion and facial morphology, although to avoid radiographic/metallic interference, those without dental restorations were preferred. This study was approved by the Ethical Committee of the Medical Faculty, University of Vienna, and each subject signed an informed consent form.

The scans were obtained using a high-resolution bone algorithm. In the present study, a computed tomogram (Tomoscan 7000R, Philips, Eindhoven, The Netherlands) was used. A yoke was mounted in the centre of the gantry which carried the X-ray tube and detectors. The X-ray tube was mounted directly opposite the detectors. The resultant attenuated X-ray beam was transmitted through the anatomical area and received and measured by the detectors. A 5.25 inch optical disc was integrated, enabling the loading of software and recording of the results, either temporarily or permanently.

The CTs were obtained using a standardized frontal plane orientation, i.e. with the subject positioned face-down with the neck hyper-extended and the scanning plane at 90 degrees to the plane of the hard palate. To minimize distortion due to poor orientation of the subject, the head was supported with a contoured pillow. In order to choose appropriate slices, a lateral overview with the proposed slices was performed with the first slice slightly anterior to the canine teeth and the last slice just posterior to the distal surface of the first permanent molars. The inter-slice distance was set arbitrarily at 1.5 mm and the slice thickness at 1.5 mm. The CT scanning process was performed only once for each subject.

Quantitation was based on two slices. For the molar slice (Figure 1) the most anterior slice showing the entire palatal root of the first maxillary molar was chosen. The canine slice was chosen as the most anterior slice on which the crown and root could be seen in their entire length (Figure 2).

Quantitative evaluation of the parameters was based on the identification and registration of a series of points (Figures 3 and 4) on standard cephalometric acetate paper using a light box (i.e. without magnification). Points 1 and 2 represent the lower limit (left and right, respectively) of the nasal cavity and are defined from a line as a tangent to the base of the nose,

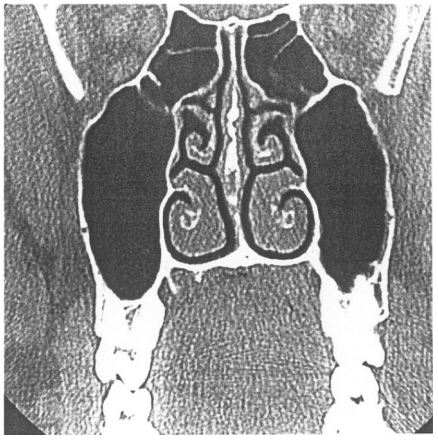

Figure 1 A computer tomographic scanning slice at the molar fulfilling the criteria for choice.

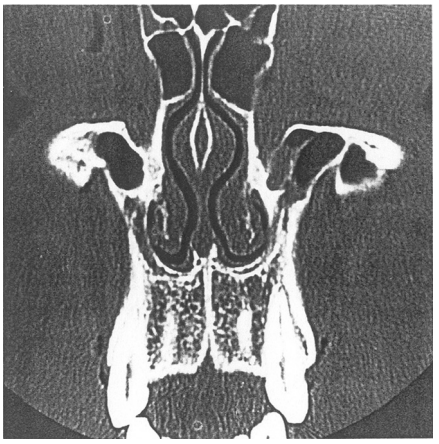

Figure 2 A computer tomographic scanning slice at the canine.

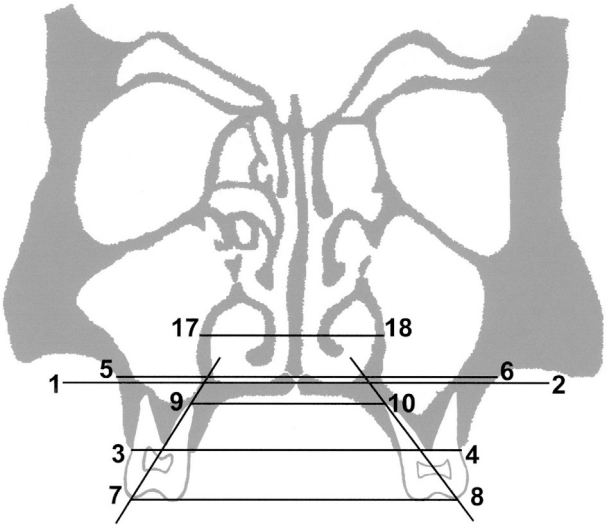

Figure 3 The parameters for the molar (see text for details).

termed the baseline 1–2: Points 3 and 4 (left and right, respectively) the most coronal points on the maxillary alveolar process on the left and right side, respectively: Points 5 and 6 the lateral limits of the maxillary base created as the point at which the almost vertical line of the alveolar process turns to the almost horizontal plane of the lower border of the zygomatic bone process: Points 7 and 8 represent the tips of the mesiobuccal cusp of the maxillary first molars, left and right, respectively: Points 9 and 10 the apices of the palatal roots of the first molars, left and right, respectively: Points 11 and 12 (Figure 4) the highest points on the crown on the maxillary canines, left and right, respectively: Points 13 and 14 (Figure 4) the apices of the maxillary canines, left and right, respectively: Points 15 and 16 (Figure 4) (for the canines) the lower limit, left and right, respectively, of the nasal cavity and are defined from a line as a tangent to the base of the nose (the baseline 15–16):

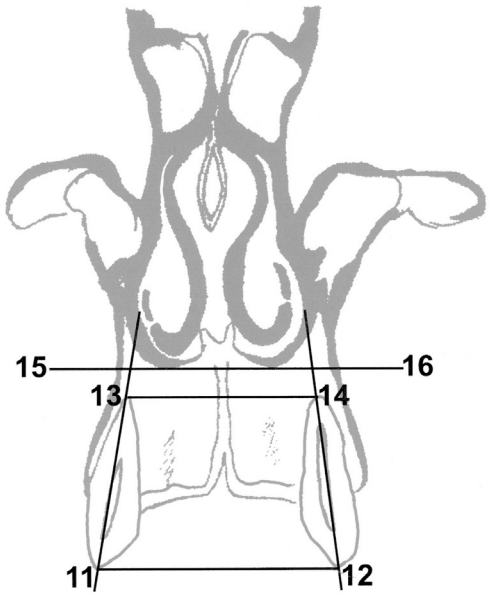

Figure 4 The parameters for the canine (see text for details).

Points 17 and 18 (Figure 3) the lateral limits of the nasal cavity: Point 17 is the lateral point on the lateral wall of the left nasal cavity using a line perpendicular to the baseline (1–2). Point 18 is constructed on the lateral wall of the right nasal cavity from point 17 using a line perpendicular to 1–2. Digitization of the points was then performed using a Scriptel© (Scriptel Corp., USA) digitizer in conjunction with a user-defined computer cephalometric analysis program (Cephaloplot©, Randers Computers, Randers, Denmark) calculating the linear and angular variables. All digitization was performed by the same person (SW). Subsequent statistical analysis was undertaken using a standard computer program (Microsoft Excel®).

Experimental procedure

The reproducibility of the digitizing process was evaluated by means of double determination of each set of registration points by the same person (BP) based on one set of recordings. In order to determine the intra-observer variation, the entire process, i.e. the selection of the registration slice, tracing and digitization, was repeated by a different author (SW) at least 10 days after the first registration. Inter-observer variation was determined by comparing the average of the two readings performed by one person with a new series of tracings (averages of double determination) by another experienced observer (SW). This process again involved all the steps of the quantitation, although the radiographic procedure was not repeated in order to minimize radiation.

In order to investigate variation due to the choice of slice, the defined parameters were measured in one patient using all the slices fulfilling the named criteria.

Statistical analysis

The statistical analysis was performed at the following stages:

(a) Differences between the two readings for both intra- and inter-observer variation were tested using a paired "Student's" *t*-test. The results for the digitization process and the intra- and inter-observer analyses are shown in Tables 1–3.
(b) The correlation between the first and second readings was calculated using Spearman's correlation analysis and represented with the *r* value. The individual differences between the first and second determinations are presented in Tables 4 and 5, respectively.

For the above statistical analysis, the material was tested for the normal requirements for using these two

Table 1 Double determination based on double point digitation by one observer ($n = 10$).

Parameter	Observation 1		Observation 2		*t*	Significance	*r*
	Mean	Variation	Mean	Variation			
1. Width of maxillary base	39.99	24.89	40.06	24.76	1.172	ns	0.99
2. Maxillary alveolar width	39.46	22.38	39.45	22.10	0.149	ns	0.99
3. Inter-molar width (apex)	21.60	11.22	21.57	10.89	0.818	ns	0.99
4. Inter-molar width (crown)	37.79	19.46	37.74	19.25	0.667	ns	0.99
5. Nasal width	22.85	5.89	22.84	5.85	0.148	ns	0.99
6. Inter-canine width (crown)	25.88	16.72	25.71	16.02	1.306	ns	0.99
7. Inter-canine width (apex)	18.94	6.11	19.08	6.09	1.401	ns	0.99
8. Right molar angulation	122.78	32.89	122.54	32.29	0.459	ns	0.96
9. Left molar angulation	122.98	35.50	123.35	21.28	1.106	ns	0.98
10. Right canine angulation	101.52	32.29	101.01	31.96	1.146	ns	0.97
11. Left canine angulation	102.63	59.84	102.09	55.02	0.914	ns	0.97

Table 2 Results of the intra-observer analysis based on double point identification (tracing on acetate paper) and digitizing by one observer ($n = 10$).

Parameter	Observation 1		Observation 2		t	Significance	σ	r
	Mean	Variation	Mean	Variation				
1. Width of maxillary base	39.99	24.87	40.09	24.38	0.684	ns	0.32	0.99
2. Maxillary alveolar width	39.46	22.38	39.56	20.88	0.400	ns	0.53	0.98
3. Inter-molar width (apex)	21.60	11.22	21.75	8.28	0.468	ns	0.68	0.97
4. Inter-molar width (crown)	37.79	14.46	37.71	17.09	0.463	ns	0.37	0.99
5. Nasal width	22.85	5.89	22.92	5.96	0.378	ns	0.40	0.97
6. Inter-canine width (crown)	25.88	16.73	25.81	16.65	0.385	ns	0.39	0.99
7. Inter-canine width (apex)	18.94	6.11	19.16	6.90	1.004	ns	0.49	0.96
8. Right molar angulation	122.78	32.89	123.48	40.55	0.738	ns	2.07	0.88
9. Left molar angulation	122.98	34.50	121.51	18.25	1.088	ns	3.05	0.98
10. Right canine angulation	101.52	32.29	101.34	43.26	0.244	ns	1.56	0.94
11. Left canine angulation	102.63	59.84	102.16	30.82	0.394	ns	2.55	0.89

Table 3 Individual differences with descriptive statistics for the evaluation of intra-observer differences. All differences expressed as positive values.

Subject	Var. 1	Var. 2	Var. 3	Var. 4	Var. 5	Var. 6	Var. 7	Var. 8	Var. 9	Var. 10	Var. 11
1	0.2	0.0	0.1	0.0	0.1	0.1	2.9	1.2	1.8	0.5	0.2
2	0.1	0.4	1.2	0.5	0.0	0.9	1.5	2.6	0.0	2.7	0.1
3	0.2	1.4	0.4	0.3	0.7	1.6	2.1	2.4	4.7	5.4	0.4
4	0.4	0.8	0.5	0.6	0.4	0.2	4.3	3.4	0.5	2.7	0.2
5	1.1	0.2	0.9	0.0	1.0	0.2	1.9	5.0	0.3	2.4	0.8
6	0.1	0.3	1.2	0.9	0.1	0.4	0.2	5.8	3.4	5.4	0.4
7	0.5	1.3	1.6	0.4	0.0	0.6	1.9	8.9	2.5	4.2	0.7
8	0.2	0.7	1.0	0.9	0.9	0.3	1.3	0.8	0.1	4.8	1.0
9	0.1	0.8	0.3	0.1	0.2	0.8	4.6	3.4	2.2	1.2	0.2
10	0.5	0.1	1.3	0.8	0.7	0.3	4.7	3.2	0.9	3.0	0.4
Mean	0.34	0.60	0.85	0.45	0.38	0.54	2.54	3.67	1.64	3.23	0.44
Maximum	1.10	1.40	1.2	0.90	1.00	0.60	4.70	8.90	4.70	5.40	1.00
Minimum	0.50	1.30	1.60	0.90	0.70	1.60	4.60	0.80	0.00	0.50	0.90
SD	0.14	0.25	0.32	0.18	0.18	0.22	0.95	0.75	0.47	1.68	0.29

SD, standard deviation.

Table 4 Inter-observer variation based on the comparison of the average of two determinations by each observer ($n = 10$).

Parameter	Observation 1		Observation 2		t	Significance	σ	r
	Mean	Variation	Mean	Variation				
1. Width of maxillary base	40.14	24.57	40.36	24.55	2.132	ns	0.67	0.98
2. Maxillary alveolar width	39.51	21.47	40.23	24.31	2.917	*	1.31	0.96
3. Inter-molar width (apex)	21.75	9.56	22.05	11.44	1.154	ns	1.32	0.96
4. Inter-molar width (crown)	37.75	18.11	38.94	27.38	1.848	ns	1.57	0.94
5. Nasal width	22.89	5.85	21.96	2.77	2.229	ns	0.57	0.97
6. Inter-canine width (crown)	25.85	16.61	24.89	13.31	1.432	ns	0.93	0.86
7. Inter-canine width (apex)	18.99	6.20	19.68	8.48	1.208	ns	0.81	0.92
8. Right molar angulation	123.13	34.57	124.15	52.79	1.213	ns	1.40	0.93
9. Left molar angulation	122.25	21.82	121.58	17.64	0.438	ns	2.05	0.43
10. Right canine angulation	101.43	36.42	103.07	86.09	0.997	ns	3.48	0.85
11. Left canine angulation	102.39	41.78	98.40	51.49	2.076	ns	3.87	0.60

ns = not significant; * $P < 0.05$.

Table 5 Individual differences with descriptive statistics for the evaluation of inter-observer analysis. All differences expressed as positive values.

Subject	Var. 1	Var. 2	Var. 3	Var. 4	Var. 5	Var. 6	Var. 7	Var. 8	Var. 9	Var. 10	Var. 11
1	0.50	0.60	0.15	0.30	0.10	1.95	0.95	2.55	0.10	0.00	3.65
2	0.75	0.00	0.40	0.75	0.45	2.30	1.55	1.25	3.50	7.70	3.65
3	0.50	2.50	5.00	4.20	1.65	0.15	0.00	0.95	2.90	4.35	4.30
4	1.00	0.70	0.45	0.40	0.40	0.90	1.50	0.75	1.30	0.75	4.65
5	0.25	0.80	0.15	0.00	0.50	1.20	0.70	2.85	1.80	10.2	11.0
6	1.55	1.65	1.40	0.10	1.15	1.15	1.30	1.00	3.80	5.30	2.80
7	0.65	1.35	0.20	2.95	0.50	0.40	1.10	0.75	3.95	2.75	0.60
8	1.80	4.25	2.70	4.50	0.45	0.95	1.55	3.35	4.40	1.55	1.30
9	0.85	1.90	0.45	1.40	1.15	0.40	1.00	2.40	1.10	3.90	9.70
10	0.55	0.55	0.05	0.60	0.40	1.85	0.95	1.75	2.70	2.35	2.90
Mean	0.84	1.43	1.09	1.49	0.67	1.125	1.106	1.96	2.565	3.885	4.455
Maximum	1.80	4.25	5.00	4.70	1.65	2.30	1.55	5.35	4.50	10.20	11.0
Minimum	0.25	0.00	0.05	0.00	0.10	0.15	0.00	0.55	0.45	0.00	0.60
SD	0.154	0.391	0.504	0.568	0.151	0.227	0.149	1.424	1.437	1.003	1.062

SD, standard deviation.

parametric tests, namely a normal distribution and homogeneity of variance.

(c) Determination of the method error was calculated using Dahlberg's formula (Dahlberg, 1940): $\sigma = \sqrt{(\Sigma d^2/2n)}$, where σ is the error of the measurement, d is the difference between the first and second readings and n is the number of subjects.

Results

The results of the repetition of the digitizing process can be seen in Table 1, expressed by the mean values and variation. For all parameters there was a slight difference between the first and second readings, although this was not statistically significant. The correlation between the first and second readings was very high, with values ranging from 0.48 to 0.98.

Correlation of the quantitation of intra-observer error is given in Table 2 (paired *t*-test and Spearman's correlation analysis). It can be seen that double registration of the radiographs by the same observer did not result in significant differences. The (average) error of the method for the linear variables (1–7) as described by σ was generally less than 0.5 mm, although linear values involving the apices of the molar and canine teeth demonstrated relatively high values. The values of *t* were generally similar to those in Table 1, although the correlation coefficients were a little lower, once again with the angular parameters demonstrating the lowest correlation coefficients. For the individual variation, very few of the linear values demonstrated a difference between the first and second readings of more than 1.0 mm, with a maximum value of 1.4 mm (Table 3). For the angular parameters, the maximum average value was 3.05 degrees.

The results of quantitation for inter-observer error are shown in Table 4 (paired *t*-test and Spearman's correlation analysis), and a summary of the individual differences between the two readings in Table 5. From Table 4 it can be seen that, with the exception of parameter 2, the maxillary alveolar width, there were no significant statistical differences between the readings of the two observers, although the *t*-values were higher than those for the intra-observer differences (Table 2). Variable 2 showed a difference corresponding to $t = 2.917$, $P < 0.05$. Both linear and angular variables demonstrated (average) values of σ that were greater than those for the intra-observer variance (Table 2). However, the greatest average value for a linear parameter was still only 1.57 mm and for the angular variable 3.87 degrees.

Considering the individual values, single differences in the linear variables of up to 5.0 mm were observed (Table 5). The angular variables also showed a greater difference than those for the intra-observer analysis. While there was no statistical difference between the readings from the two observers, single differences of up to 7.7 degrees could be seen. In all cases, the differences between the first and second readings showed a reasonable distribution of positive and negative values (although for statistical purposes represented by positive results in the respective tables).

The effect of choosing alternative slices which still fulfilled the criteria for quantitation, although not being the most anterior slice, is shown in Figure 5a, b. For both the angular and linear variables very little variation existed, and the size of the difference between the slices did not exceed the differences that could be expected when remeasuring a chosen slice.

Discussion

As stressed by Vanarsdall and White (1992), the lateral dimension can be regarded as the 'forgotten dimension' of dentofacial analysis, due partly to the lack of simple

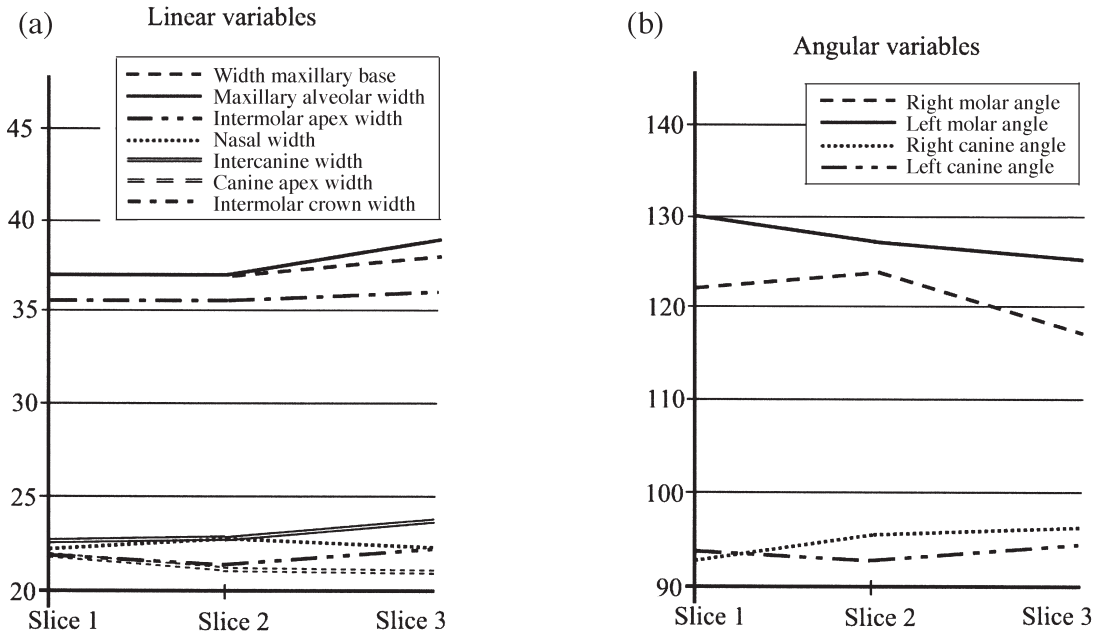

Figure 5 Variation in dimensions for several slices, each fulfilling the criteria for selection. (a) Linear variables (mm). Maxillary alveolar width: 3–4; maxillary base: 5–6; inter-molar width (apex): 9–10; inter-molar width (crown): 7–8; nasal width: 17–18; inter-canine width (crown): 11–12; inter-canine width (apex): 13–14. (b) Angular variables (degrees). Right molar angulation: 7–9/1–2; left molar angulation 8–10/1–2; right canine angulation 1–13/15–16; left canine angulation 12–14/15–16.

registration corresponding to the lateral cephalogram in sagittal and vertical analysis. As such it can be anticipated that the transverse dimension, and not least its quantitation, will be the focus of future studies.

Tomographic scanning has already been used in orthodontic diagnosis (Fuhrmann *et al.*, 1994), in connection with cleft palate subjects, the temporomandibular joint (Seren *et al.*, 1994; Moaddab *et al.*, 1985) and in the case of ectopic canine teeth (Ericson and Kurol, 1988; Schmuth *et al.*, 1992). The possibilities for CT scanning of transverse discrepancies were recommended by Timms (1982) after a pilot study, although his investigation was based on axial scanning. In orthodontic diagnosis and treatment planning it is customary to differentiate between skeletal structures, the morphology and size of which are thought to be largely genetic, and dento-alveolar structures, i.e. the structures immediately surrounding the teeth and dependent on the presence of the teeth and the surrounding environment (Solow, 1980). The efficiency of orthopaedic and orthodontic appliances is usually based on observed changes in these areas.

All forms of quantitation raise questions as to the validity and reproducibility of the structures measured. For standard cephalometric analyses used in orthodontic diagnosis, these have been well reported by Baumrind *et al.* (1971a,b). The present study aimed to investigate reproducibility at three levels, namely the process of digitization as well as intra- and inter-observer variation. It must also be realized that another source of error would arise from the placement of the patient in the scanner. For ethical reasons, double determination at that level was not possible.

The process of digitization revealed that although there were no significant differences between the first and second readings, some variation in values could be expected. The weakness of the digitizer in quantitation has been described by Eriksen and Solow (1991) and, consequently, the reproducibility of the digitizer and the digitizing process has to be rigorously controlled.

Intra-observer variation revealed no significant variation between the first and second readings, only very small individual variations, both positive and negative, were seen. These values correspond well (subjectively) with those for standard cephalometric reference points (Baumrind *et al.*, 1971b).

The results of the inter-observer analysis showed, as would be expected, greater variation, although with the exception of one parameter, representing the maxillary alveolar width, statistically significant differences were not seen (no reason for the slight significance in variable 2 can be given, but the phenomenon of mass significance, occurring when statistical tests are repeated continually, could be the answer). The variation between observers was small compared with the biological variation from subject to subject.

In general the errors for the angular parameters were larger than for the linear variables, which seems reasonable, as each parameter is constructed on three points each with its own variation. The small distance

between the points involved will also tend to increase the error. The variation in the angular values corresponds well with similar values based on reproducibility in standard cephalometrics (Baumrind *et al.*, 1971b), where parameters involving the apices of teeth seem least reproducible, as found in the present study.

The measurements performed in this experiment could have been carried out on dry skulls. It was, however, decided to perform the study on living patients in order that the experimental set-up, including the process of placing the patient in the CT scanner, could be included in the source of variation.

The interpretation and use of the results of this study are important. Methodological variation must be seen in relation to the use to which the parameters are to be put. In diagnosis where the individual patient is compared with 'standard values' obtained from a particular control population, the methodological variation (error) must be smaller than the biological variation between the individuals that comprise the control population. When evaluating the effect of therapy on the dimensions measured, it is necessary to relate the methodological error to the expected effect of the therapy. In both cases, an understanding of the size of the methodological error will be important in interpreting results, not least negative results.

Conclusions

The results of the present study indicate that the system described represents a reasonable method by which the transverse morphology of the maxillary structures can be described. The difference between intra- and inter-observer variation indicates that when possible, all quantitation should be performed by the same person. Based on the findings regarding values for single patients of a few, although relatively large, differences in inter-observer variation, the method would be better for comparisons of groups using average values than for individuals.

The method constitutes a useful supplement to orthodontic diagnosis, not least considering the extreme weakness of all other methods available and can, therefore, be recommended.

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