A comparison of three superimposition methods

Q. L. You and U. Hägg
Orthodontics, Faculty of Dentistry, The University of Hong Kong

SUMMARY The purpose of this investigation was to compare the reliability of three super-imposition methods: Björk's structural, Ricketts' four-position, and Pancherz's method. The material consisted of 14 pairs of cephalograms obtained before and after Herbst treatment. Each pair of cephalograms were traced and superimposed by means of the three different methods three times each. A reference grid was used to quantitatively evaluate the sagittal dental and skeletal changes.

The results revealed that: (1) there was no statistically significant difference between the repeated measurements in the three methods, i.e. all three methods were reliable. (2) There was no significant difference among the three superimposition methods to evaluate the sagittal skeletal and dental changes. (3) Comparing the coefficient of reliability, none of the three methods was suitable for individual assessment, and Pancherz's method only was acceptable for assessment of patients in groups.

Introduction

Cephalometry is important not only for the diagnosis, but also for the evaluation of ortho-dontic treatment. In many instances, an adequate orthodontic diagnosis can be made without a cephalogram. However, it is practically impos-sible to assess accurately a patient's response to treatment and/or growth changes without being able to compare serial lateral cephalograms.

Treatment response and/or growth changes are measured by superimposition of serial tracings on relative stable bases or regional contours (Graber, 1994). Many different superimposition methods have been described in the literature (e.g. Broadbent, 1931; DeCoster, 1953; Steiner, 1953; Björk, 1963; Björk and Skieller, 1977; Ricketts, 1975; Pancherz, 1982; Johnston, 1986). Since each of them has its own specific references system, potentially they will lead to different interpretations of the changes taking place in the craniofacial complex over a given period of time as a result of growth and/or the effects of ortho-dontic treatment (Ghafari *et al.*, 1987; Ghafari and Efstratiadis, 1989; Cangialosi *et al.*, 1994). There are two main categories of orthodontic patients: growing and non-growing. Growth changes of the reference structures used for superimposition must be taken into consideration for growing patients.

Errors in cephalometrics are inherent and unavoidable. They can derive from various sources and arise at any stage of the cephalometric procedure. The specific errors associated with cephalometric superimposition can be attributed to growth and remodelling at the reference planes (Björk, 1969; Björk and Skieller, 1977), as well as to the reproducibility of superimposition on that plane itself (Baumrind *et al.*, 1976; Houston and Lee, 1985). Other factors include landmark identification and tracing errors, as well as errors inherent in the cephalometric imaging technique itself (Hixon, 1956; Baumrind and Frantz, 1971a,b; Gravely and Benzies, 1974; Cohen, 1984). Many articles have been published on the relative inaccuracy of different cephalo-metric superimposition methods (e.g. Baumrind *et al.*, 1976; Houston, 1983; Pancherz and Hansen, 1984; Houston and Lee, 1985; Ghafari and Efstratiadis, 1989). None of the superimposition methods studied seemed to be superior.

Björk's structural method (Björk, 1963; Björk and Skieller, 1977) and Ricketts' four-position

method (Ricketts, 1975) are the two commonly used superimposition methods, since they display the changes in diagrams, i.e. they are devised for the assessment of changes in an individual patient rather than groups of patients. Some comparison studies have been made on the reliability and/or validity of these two methods (Nielsen, 1989; Ghafari and Efstratiadis, 1989; Cook *et al.*, 1994; Doppel *et al.*, 1994). However, the conclusions differ. Nielsen (1989) suggested Björk's method for its relatively higher reliability and accuracy, while Cook *et al.* (1994) preferred Ricketts' method, for none of them was superior and Ricketts' four-position method was easier. Pancherz's superimposition method (Pancherz, 1982) makes it possible to quantitatively evaluate the sagittal skeletal and dental changes. However, no data are available to substantiate the reliability of this method and to compare it with the other superimposition methods.

In reliability studies, means, standard deviations, and their statistical evaluation may indicate a systematic error rather than assure the precision of the repeated measurements. Coefficient of reliability seems to be a better way to assess whether a method is suitable for individual or sample assessment (Healy, 1958; Winer, 1971; Baughan *et al.*, 1979).

The aim of this study was to evaluate and compare the reliability of the three cephalometric superimposition methods: Björk's structural (Björk, 1963; Björk and Skieller, 1977), Ricketts' four-position (Ricketts, 1975), and Pancherz's method (Pancherz, 1982).

Materials and methods

The material consisted of pairs of lateral cephalograms obtained from 14 patients before and after treatment with the Herbst appliance. The average time between the two cephalograms was 7.5 months with a standard deviation of 2.3 months.

Björk's method (Björk, 1963; Björk and Skieller, 1977) is based on the results from a series of implant studies. Björk and Skieller (1977) concluded that the anterior surface of the zygomatic process remained unchanged during growth. Thus, superimposing the cephalograms on this structure could be used to detect the maxillary skeletal, dental, and the mandibular skeletal changes with skeletal remodelling (Figure 1a). In another study, Björk (1963) concluded that mandibular dental changes were better detected by superimposing the cephalograms on the stable natural reference structures: (1) inner cortical structure of the inferior border of the symphysis; (2) detailed structures of the mandibular canal; and (3) lower contour of the third molar germ before root development begins (Figure 1b).
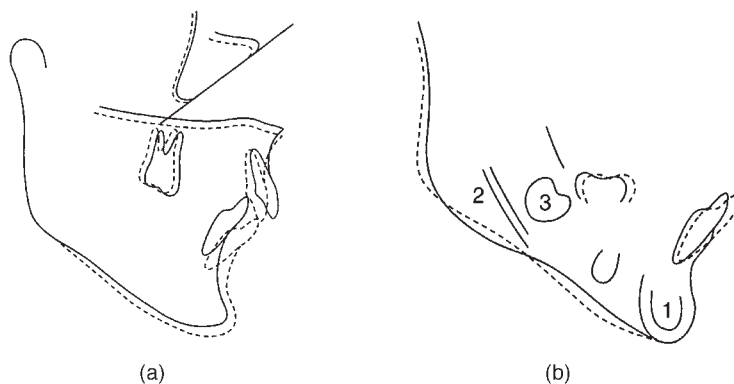

(a)   (b)

Figure 1   Björk's superimposition method. (a) Superimposed on the anterior surface of zygomatic surface. (b) Superimposed on the nature reference structures: (1) inner cortical structure of the inferior border of the symphysis; (2) detailed structures of the mandibular canal area; (3) lower contour of the molar germ before root development begins.
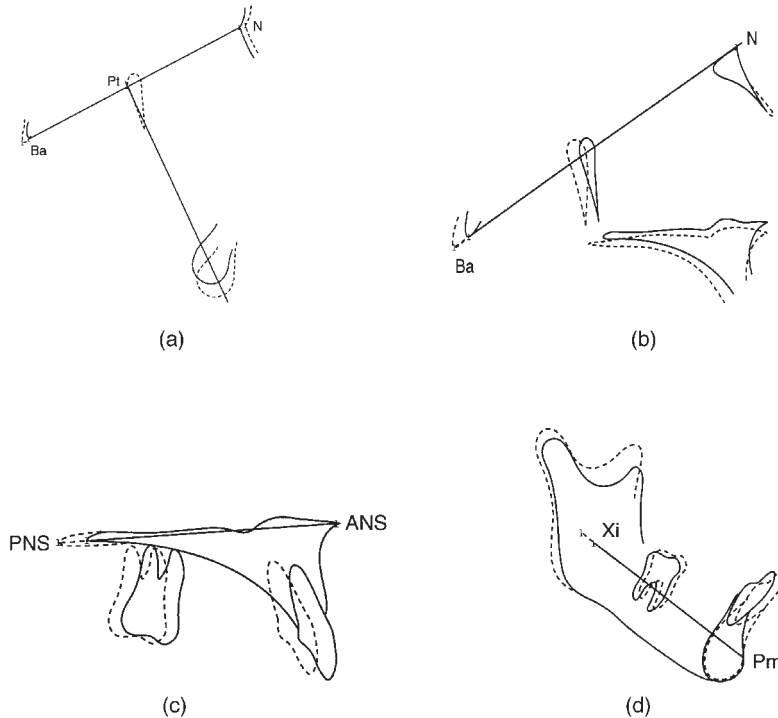
Figure 2 Ricketts' superimposition method. (a) Position I. (b) Position II. (c) Position III. (d) Position IV. Definition of the references: Ba (basion): anterior border of foramen magnum; Pt (pterygoid): lower lip of foramen rotundum; ANS (anterior nasal spine): apex of the anterior spine; PNS (posterior nasal spine): apex of the posterior spine; Xi (centroid of the ramus): halfway point between the lowest point of the sigmoid notch and a point immediately inferior to it on the lower border of the ramus in the Frankfort horizontal orientation; Pm (protuberance menti): top of the crest of the bony cortex in the outline of the symphysis in the area of the mental protuberance; BaN: the line through N and Ba; PP: the line through ANS and PNS; corpus axis: the line through Xi and Pm.

Ricketts' method (Ricketts, 1975) comprises four steps to evaluate orthodontic treatment. Positions I and II are used to display the mandibular and maxillary skeletal changes, the lateral cephalograms are superimposed on BaN at Pt and N, respectively (Figure 2a, b). Positions III and IV are used to show the maxillary and mandibular dental changes, the superimpositions are made on PP at ANS and the corpus axis at Pm, respectively (Figure 2c, d).

Pancherz's method (Pancherz, 1982) can be used to quantitatively evaluate sagittal skeletal and dental changes. A reference grid is established by the occlusal plane (OL) and its perpendicular plane (OLp) through sella point on the initial cephalogram. Cephalograms are superimposed on SN at S (Figure 3). Maxillary and mandibular skeletal changes are measured from the movement of the representative landmarks along the initial OL plane to OLp. Maxillary and mandibular dental changes are obtained from the movement of the dental landmarks along OL plane to OLp, subtracting the movement of their related skeletal basis.

Analysis procedures

The pre- and post-treatment cephalograms were traced on conventional translucent acetate paper, using a trans-illuminating light box in a darkened
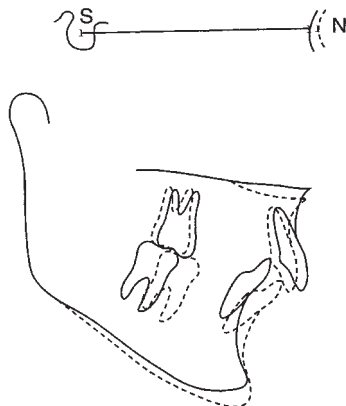
Figure 3 Pancherz's superimposition method. Definition of the references: S (sella): the centre of sella turcica; N (nasion): the most anterior limit of suture nasofrontalis; SN: the line through S and N.

Figure 4 The skeletal and dental landmarks relative to the reference grid in this study. (1) A (subspinale): the deepest point on the anterior contour of the maxillary alveolar projection determined by a tangent perpendicular to OL; (2) B (supramentale): the deepest point on the mandibular symphysis between infradentale and pogonion determined by a tangent perpendicular to OL; (3) Pg (pogonion): the most anterior point on the bony chin determined by a tangent perpendicular to OL; (4) U1 (upper incisor tip): the incisal tip of the most prominent mandibular central incisor; (5) U6 (lower molar tip): the mesial contact point of the maxillary permanent first molar determined by a tangent perpendicular to OL. Where double projection gave rise to two points, the mid-point was used; (6) L1 (lower incisor tip): the incisal tip of the most prominent maxillary central incisor; (7) L6 (lower molar tip): the mesial contact point of the mandibular permanent first molar determined by a tangent perpendicular to OL. Where double projection gave rise to two points, the mid-point was used.

room. No more than three sets of radiographs were traced in a session to avoid operator fatigue. The retracing of the cephalograms was undertaken with at least a 1-week interval to avoid memorization of the landmarks.

In order to evaluate quantitatively the changes for all the three methods, a reference coordinate system similar to the one described by Pancherz (1982) was used. On the pre-treatment cephalograms, the occlusal plane (OL), which was defined as a line through the incisor tip of the most prominent maxillary central incisor and the distal-buccal cusp of the maxillary permanent first molar, was used as the *x*-axis, and a line perpendicular to this plane (OLp) through point S as the *y*-axis.

On the pre-treatment tracing, all the landmarks and the structures for all the three methods and the reference grid were marked, and all the landmarks and the structures for all the three methods were also marked on the post-treatment tracings.

The post-treatment tracings were then superimposed on the pre-treatment tracings three times by hand according to the three different methods, and the grids were subsequently transferred to the post-treatment tracings.

Lastly, the positions of each of the selected landmarks were measured along the OL plane to OLp within the coordinate system. The dental and skeletal changes were calculated and recorded according to the three different superimposition methods.
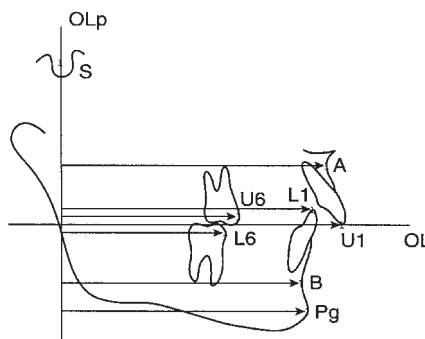
The tracings and the measurements were repeated three times (Trials I, II, and III). All the tracings and measurements were performed by one author with 6 years orthodontic experience (QLY).

The landmarks used in this study and their positions related to the co-ordinate system are shown in Figure 4.

Statistical analysis

The three sets of skeletal and dental changes (Trials I, II, and III), their means, and the standard deviations obtained by means of the three superimposition methods were established mathematically by computer. The means and standard deviations of each trial were statistically analysed by one-way ANOVA for the three

Table 1 Analysis of reproducibility of Björk's method.

	Trial I		Trial II		Trial III			
	Mean	SD	Mean	SD	Mean	SD	*F* value	*P* value
A	0.21	3.14	−0.04	3.00	0.04	3.10	0.02	0.976
B	3.64	5.09	3.61	4.33	3.61	2.97	0.00	1.000
Pg	3.93	6.17	3.25	5.15	4.00	3.62	0.09	0.912
U1	−3.86	4.88	−2.54	3.47	−2.29	2.78	0.69	0.509
U6	−2.25	3.91	−3.00	3.21	−2.36	2.62	0.21	0.809
L1	2.07	1.65	1.93	2.01	1.93	2.45	0.02	0.978
L6	1.18	1.68	0.89	2.11	1.11	1.44	0.10	0.906

Table 2 Analysis of reproducibility of Ricketts' method.

	Trial I		Trial II		Trial III			
	Mean	SD	Mean	SD	Mean	SD	*F* value	*P* value
A	−0.07	1.25	0.54	1.78	0.68	1.89	0.80	0.456
B	2.39	1.66	2.93	2.04	2.43	2.00	0.35	0.710
Pg	2.36	1.84	2.32	2.27	2.21	2.17	0.02	0.983
U1	−2.46	2.26	−2.61	2.40	−2.86	2.90	0.09	0.918
U6	1.96	2.65	1.93	2.13	1.68	2.65	0.07	0.934
L1	−2.75	2.16	−2.61	2.07	−2.89	1.87	0.05	0.947
L6	1.21	1.98	1.36	1.72	1.32	2.08	0.02	0.980

individual methods. Also, for the three individual superimposition methods, the means and standard deviations of the three trials were calculated by the computer. The ANOVA test was used for the statistical analysis among these methods. One-way analysis of variance (ANOVA) was used under the assumption that the samples were drawn from normal populations.

The reliability coefficient used was Cronbach's alpha (α). Alpha (α) is based on the 'internal consistency' of a test. That is, it is based on the average correlation of items within a test, if the items are standardized to a standard deviation of 1.

All data were analysed using SAS® for Windows™ Release 6.11 (SAS Institute Inc., Cary, North Carolina, USA) and Instat® 3.0 (Graph Pad Software Inc., San Diego, California, USA) software. The difference was considered statistically significant at $P < 0.05$.

Results

All data in each method were normally distributed (Shapiro-Wilk *W* test, $P > 0.05$).

There was no significant difference ($P > 0.05$) for the reliability test in any of the three individual methods (Tables 1–3). The standard deviations for Björk's method (Table 1) were, in general, larger than for the other two methods (Tables 2 and 3).

Comparing the superimposition methods, there was no statistically significant difference ($P > 0.05$) among the three methods for any of the skeletal and dental measurements investigated (Table 4).

Coefficients of reliability (Table 5) were, in general, higher for Pancherz's method than for the other two methods, with Björk's method being the lowest. For Pancherz's method, five out of the seven measurements reached the 0.90

Table 3 Analysis of reproducibility of Pancherz's method.

| | Trial I | | Trial II | | Trial III | | | |
	Mean	SD	Mean	SD	Mean	SD	F value	P value
A	0.36	1.34	0.32	1.78	0.36	1.34	0.00	0.997
B	2.46	2.09	2.64	2.24	2.32	2.58	0.07	0.934
Pg	2.18	2.55	2.11	2.42	2.46	2.98	0.07	0.932
U1	–2.61	2.48	–2.29	2.94	–2.21	2.64	0.08	0.919
U6	–2.64	1.81	–3.14	2.61	–2.39	1.39	0.51	0.604
L1	2.50	1.72	2.89	1.82	2.57	2.00	0.18	0.837
L6	1.39	1.26	1.89	1.11	1.61	1.50	0.52	0.597

Table 4 The comparison of the three different superimposition methods.

		Mean	SD	F value	P value
A	Björk	0.07	2.91	0.10	0.908
	Ricketts	0.38	1.47		
	Pancherz	0.35	1.33		
B	Björk	3.62	3.45	0.87	0.429
	Ricketts	2.58	1.67		
	Pancherz	2.48	2.16		
Pg	Björk	3.73	4.08	1.13	0.333
	Ricketts	2.30	1.83		
	Pancherz	2.25	2.48		
U1	Björk	–2.89	2.57	0.16	0.850
	Ricketts	–2.64	2.20		
	Pancherz	–2.37	2.48		
U6	Björk	–2.54	2.75	0.05	0.955
	Ricketts	–2.75	1.53		
	Pancherz	–2.73	1.67		
L1	Björk	1.98	1.89	0.66	0.525
	Ricketts	1.86	2.34		
	Pancherz	2.65	1.68		
L6	Björk	1.06	1.32	0.61	0.546
	Ricketts	1.30	1.66		
	Pancherz	1.63	1.06		

Table 5 Coefficient of reliability of the three superimposition methods.

	Björk	Ricketts	Pancherz
A	0.94	0.86	0.87
B	0.75	0.84	0.93
Pg	0.72	0.93	0.93
U1	0.80	0.84	0.93
U6	0.79	0.62	0.72
L1	0.90	0.94	0.98
L6	0.60	0.83	0.93

lower for landmarks B and Pg for Björk's method compared with the other two methods.

Discussion

In this study, a sample of patients treated with the Herbst appliance was chosen, since there is unlikely to have been any growth effect on the various reference structures used for superimposition, but there were substantial dental and skeletal changes during the short treatment period (Pancherz, 1985). With this approach, the evaluation comprised the reliability of the treatment changes assessed by the three various methods and the suitability, rather than the stability of the reference structures used for superimposition.

This study addressed the intra-observer reliability only. According to some studies, intra-observer reliability is less than inter-observer

level and one of the remaining two approached that level. The only measurement that reached the level of 0.95 in the three methods was L1 in Pancherz's method, but was close to Ricketts' method (0.94).

Overall, the highest and lowest coefficients were found in dental landmarks, L1 and U6, respectively.

For the skeletal measurements, the coefficient of reliability was higher for landmark A, and

reliability (e.g. Hixon, 1956; Stabrun and Danielsen, 1982; Lau *et al.*, 1997), although others report that the errors are of the same magnitude (e.g. Savara *et al.*, 1966).

The purpose of this investigation was to compare three superimposition methods, not to evaluate specifically the errors of individual landmark location.

The superimposition methods studied used two different ways to evaluate the changes during orthodontic treatment. Two of the methods, Björk's structural method (Björk, 1963; Björk and Skieller, 1977) and Ricketts' four-position method (Ricketts, 1975), display the skeletal and dental changes in diagrams, and are, in principle, devised for assessment of individual patients. Pancherz's method (Pancherz, 1982) is used for quantitative evaluation of skeletal and dental changes occurring along the occlusal plane. For the three superimposition methods, different reference structures or planes are used, i.e. anatomical structures in Björk's method, between cephalometric landmarks in Pancherz's method, and some constructed landmarks in Ricketts' method.

In order to be able to evaluate the reliability for each of the three methods and to compare them, a reference grid (Pancherz, 1982) was used in this study. This reference grid was close to the area of interest and would not be affected by the treatment, since it was constructed on the initial cephalogram taken prior to treatment and was transferred to the second cephalogram taken after treatment. Although this limited the study to the sagittal skeletal and dental changes of selected cephalometric landmarks, it is the horizontal component during growth, along with horizontal tooth movements along the functional occlusal plane, that is decisive for the treatment outcome of anterior-posterior occlusal discrepancies (Johnston, 1986).

The results of the present study showed that all the three superimposition methods compared were reliable (Tables 1–3), which confirmed the results reported for the two methods (Björk's and Ricketts') previously (Nielsen, 1989; Cook *et al.*, 1994). Moreover, no significant difference between the three methods was found in this investigation (Table 4). Although the dental and skeletal mean changes expressed numerically were in general small, especially compared with the standard deviations (Tables 1–4), the results, based on a one-way ANOVA test, showed that there was no statistically significant systematic error for any of the individual methods (Tables 1–3). There was no difference in that aspect among the three methods (Table 4). However, the magnitude of the standard deviations reflecting the series of assessments of the skeletal and dental changes made on individuals was imprecise, and may differ between the methods. For example, the standard deviations for Björk's method (Tables 1 and 4) were larger than for the other two methods (Tables 2–4). The ANOVA did not show any statistically significant differences in the reliability tests (Tables 1–4), indicating that there was no statistically significant systematic error in the changes measured by the three different methods, rather than assuring that the repeated measurements of the treatment changes were precise. To overcome this problem Baughan *et al.* (1979) recommended the use of a coefficient of reliability as a way to assess whether or not a cephalometric measurement is suitable for individual or group assessment. If the coefficient of reliability drops below 0.95, individual assessment becomes very irregular, while if it drops below 0.90, even mean assessment for groups is of little use. The results of the present study (Table 5) showed that none of the three superimposition methods reached the standard for assessment of treatment changes in individuals, and only one of the methods, devised by Pancherz (1982), can be recommended for assessment of treatment changes in samples. However, this was on the assumption that the changes measured were of similar or larger magnitude than those in the present sample.

All seven landmarks as well as the grid used in this study for the evaluation of the dental and skeletal changes during Herbst treatment were the same for all the three superimposition methods. Consequently, the errors related to the identification of those seven landmarks were the same for all the three methods, thus the outcome of the assessment of the three superimposition methods was solely based on the errors related to the various reference structures

and planes used. Those errors were: (1) the identification of the landmarks of the references and structures; (2) the distance between the landmarks used for construction of a reference line or the length of the reference structure; and (3) the distance between the reference lines, structures, and the landmarks used for the assessment of the treatment changes. The smaller the error in landmark identification, the longer the reference plane, and the closer the landmark used for assessment to the reference plane, the more precise the method would be.

It seemed that the longer reference plane (Ba–N) used by Ricketts (1975) was not superior to the shorter reference plane (SN) used by Pancherz (1982; Table 5). This was because the reliability of basion (Ba) was considerably lower than that of sella (S) (Kathopoulis *et al.*, 1993). The closeness of the reference structure to point A might explain why the coefficient of reliability was higher for this specific landmark for Björk's method than for the other two methods (Table 5). The same reference structure seemed not secure changes of the position of the skeletal landmarks in the mandible, probably due to the longer distance between the structure and those landmarks, and the relatively short reference structure itself. The superimposition on natural structures (Björk's method) or constructed planes (Ricketts' method) did not increase the coefficient of reliability for the dental landmarks compared with the use of the SN plane (Pancherz's method).

In general, skeletal landmarks are considered to be more reliable than dental landmarks (e.g. Baumrind and Frantz, 1971a,b; Chan *et al.*, 1994; Tng *et al.*, 1994). Following the changes in the incisor angles, which were based on four landmarks, two skeletal and two dental were less reliable than the angles based on three skeletal landmarks only. In fact, changes of incisor position on individual patients were in general too small to be assessed by the incisor angles (Baumrind and Frantz, 1971a,b; Chan *et al.*, 1994; Tng *et al.*, 1994). In this study, when the change of the position in the incisors was assessed by the tip of the incisors, the coefficient of reliability was very high, even reaching (mandibular incisors) or approaching (maxillary incisors) the level

acceptable for individual assessment (Baughan *et al.*, 1979), but for Pancherz's method only.

The results of the study showed that different superimposition methods might affect the evaluation of orthodontic treatment. They also confirmed that the anterior skull base (SN) was a superior reference plane compared with the other planes and structures investigated in this study. It was also shown that, compared with superimpositions made on the maxilla and mandible, more reliable assessment of the changes of the position of the teeth in both the maxilla and the mandible could be obtained when the anterior skull base was used as a reference.

Conclusions

The method devised by Pancherz (1982) seems to be the only suitable method, among those compared, to assess changes in orthodontic treatment, but for group rather than individual assessment.

Address for correspondence

Q. L. You
Department of Orthodontics
School of Stomatology
Shanghai Second Medical University
No. 9th People's Hospital
639# Zhi Zao Ju Road
Shanghai
China

Acknowledgements

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